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The Journal of
THE ROYAL AERONAUTICAL SOCIETY

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AUGUST 1951

PLANNING AND PRODUCTION METHODS USED IN THE CONSTRUCTION OF THE DE HAVILLAND COMET

H. POVEY, A.F.R.Ae.S.

REVIEWS

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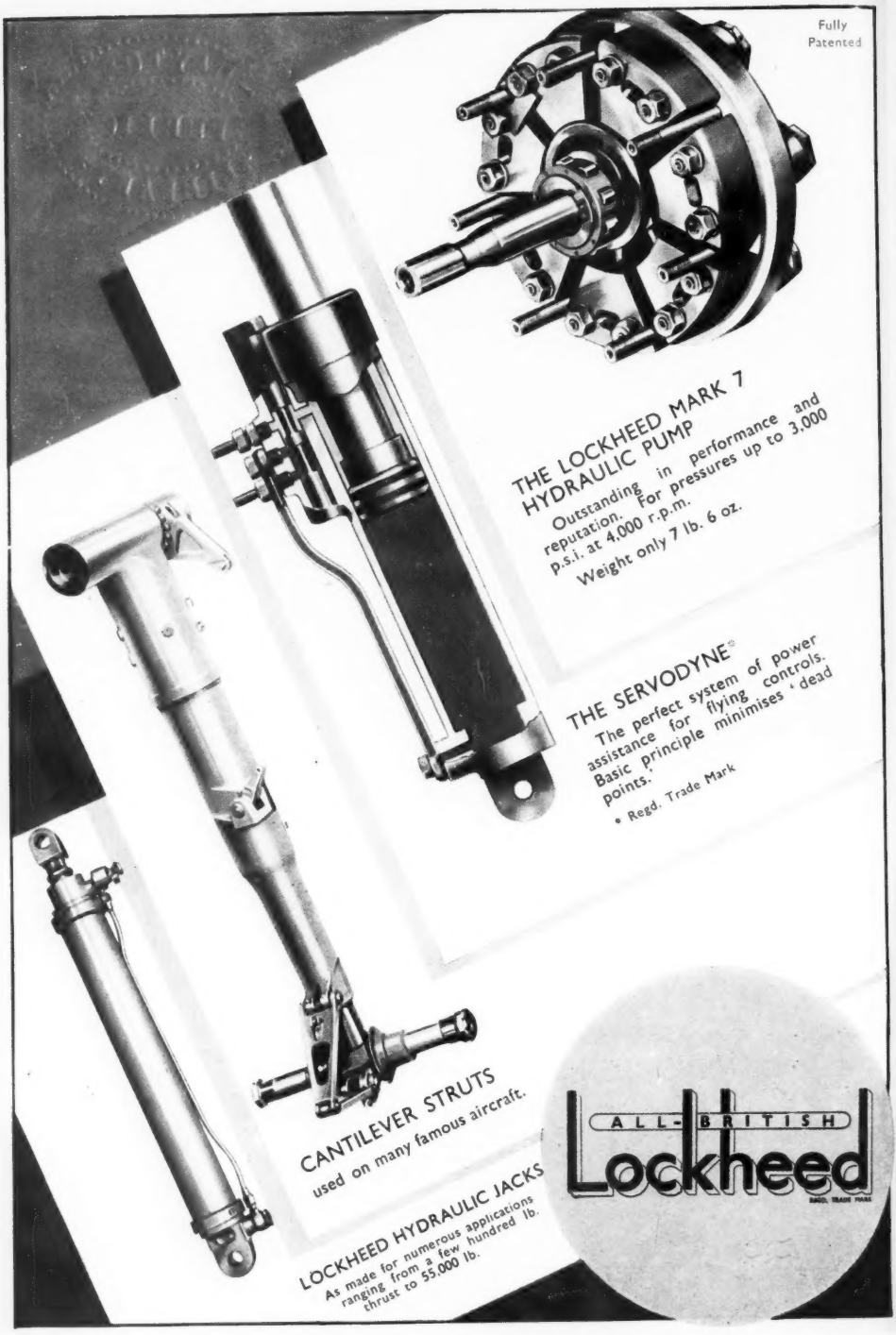
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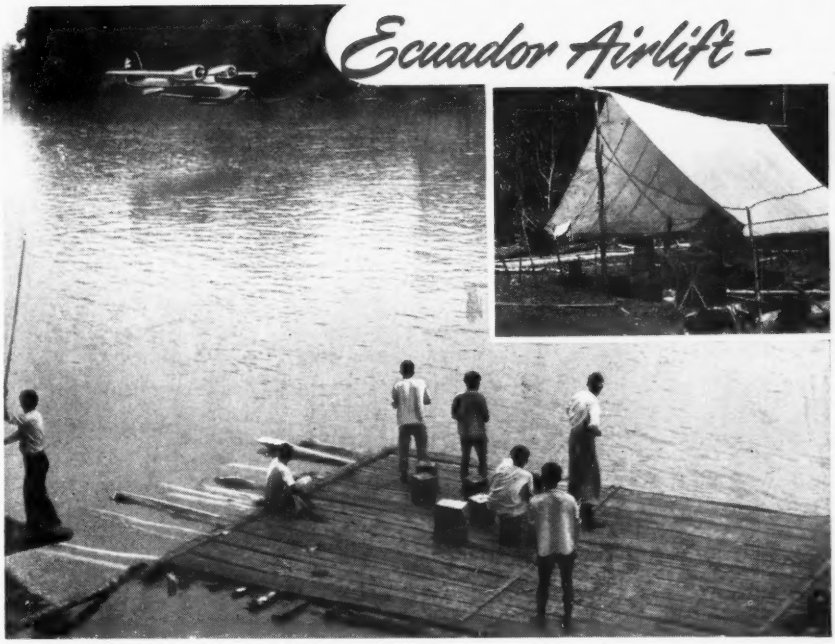

(Above) A Grumman amphibian aircraft lands on the Aguarico river near a survey camp in the Oriente region of Ecuador.

(Inset) A typical scene in a survey camp in the Oriente region of Ecuador.

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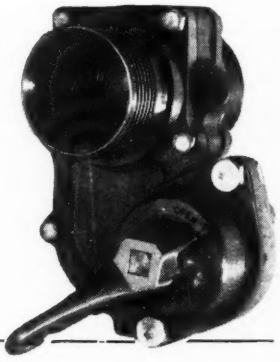

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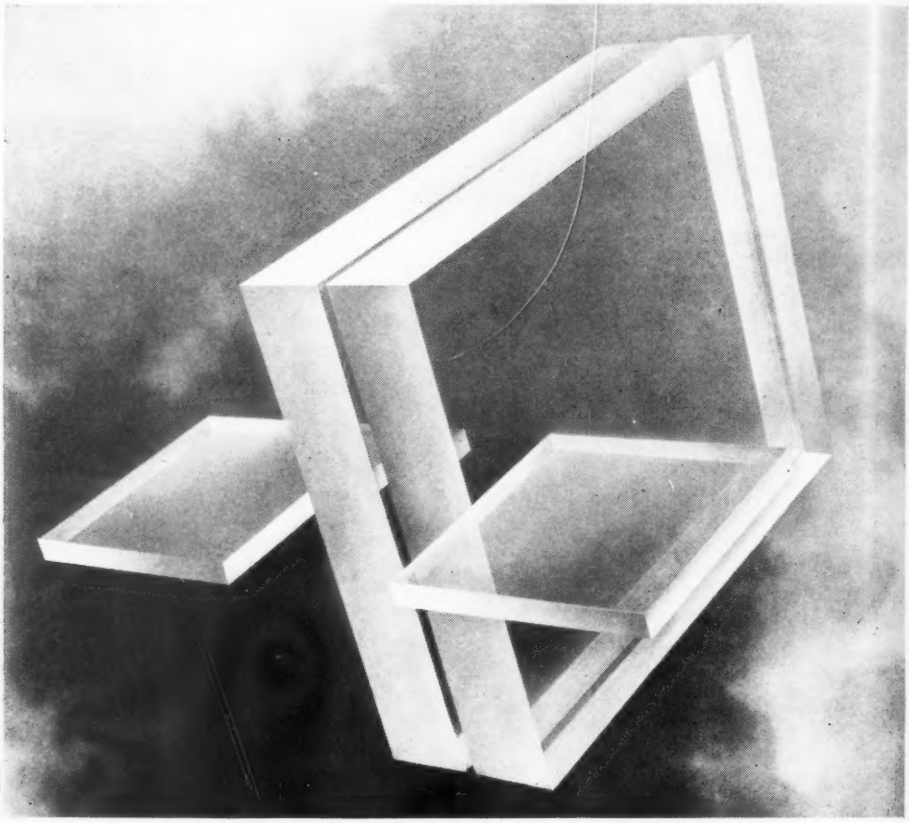

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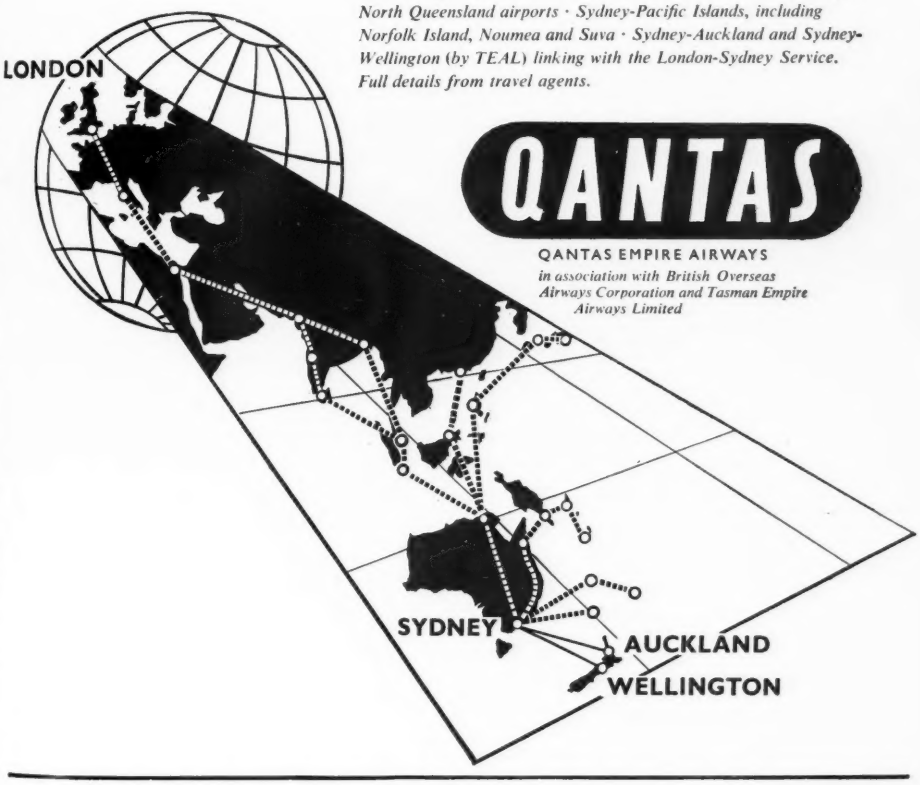

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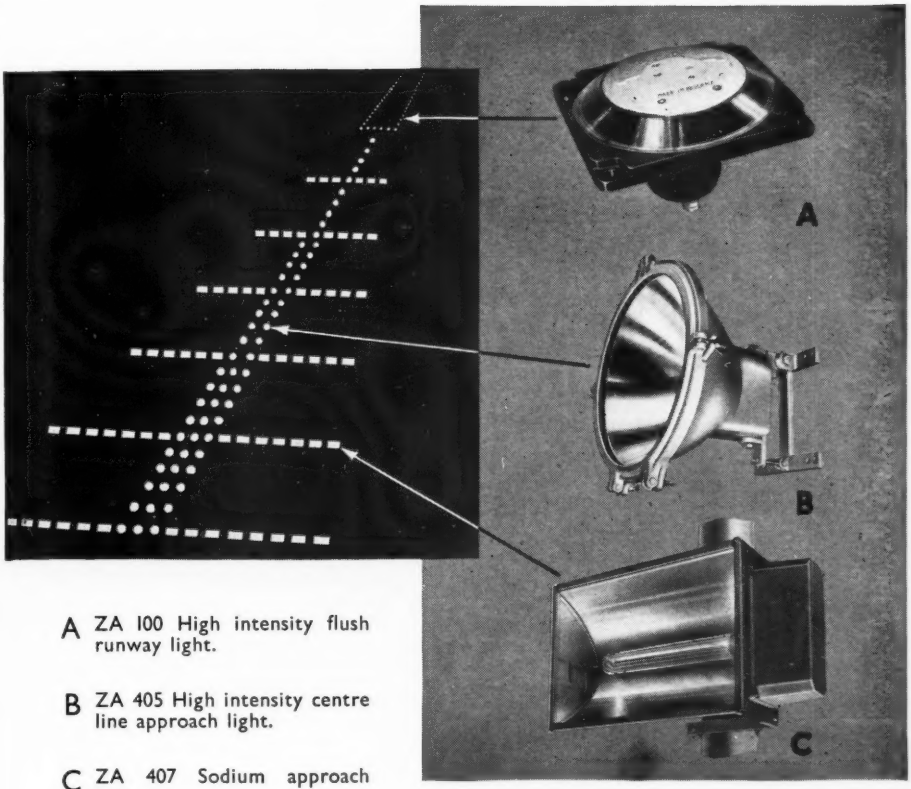

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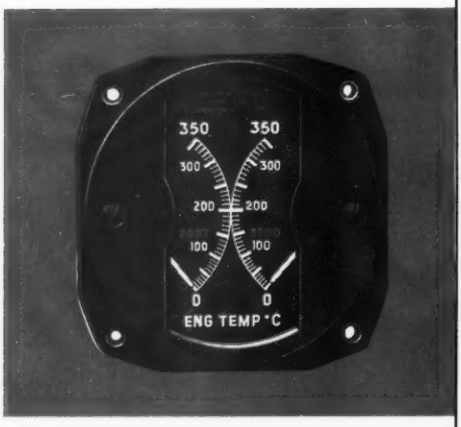

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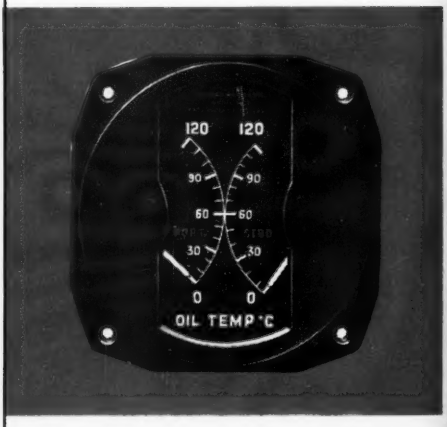

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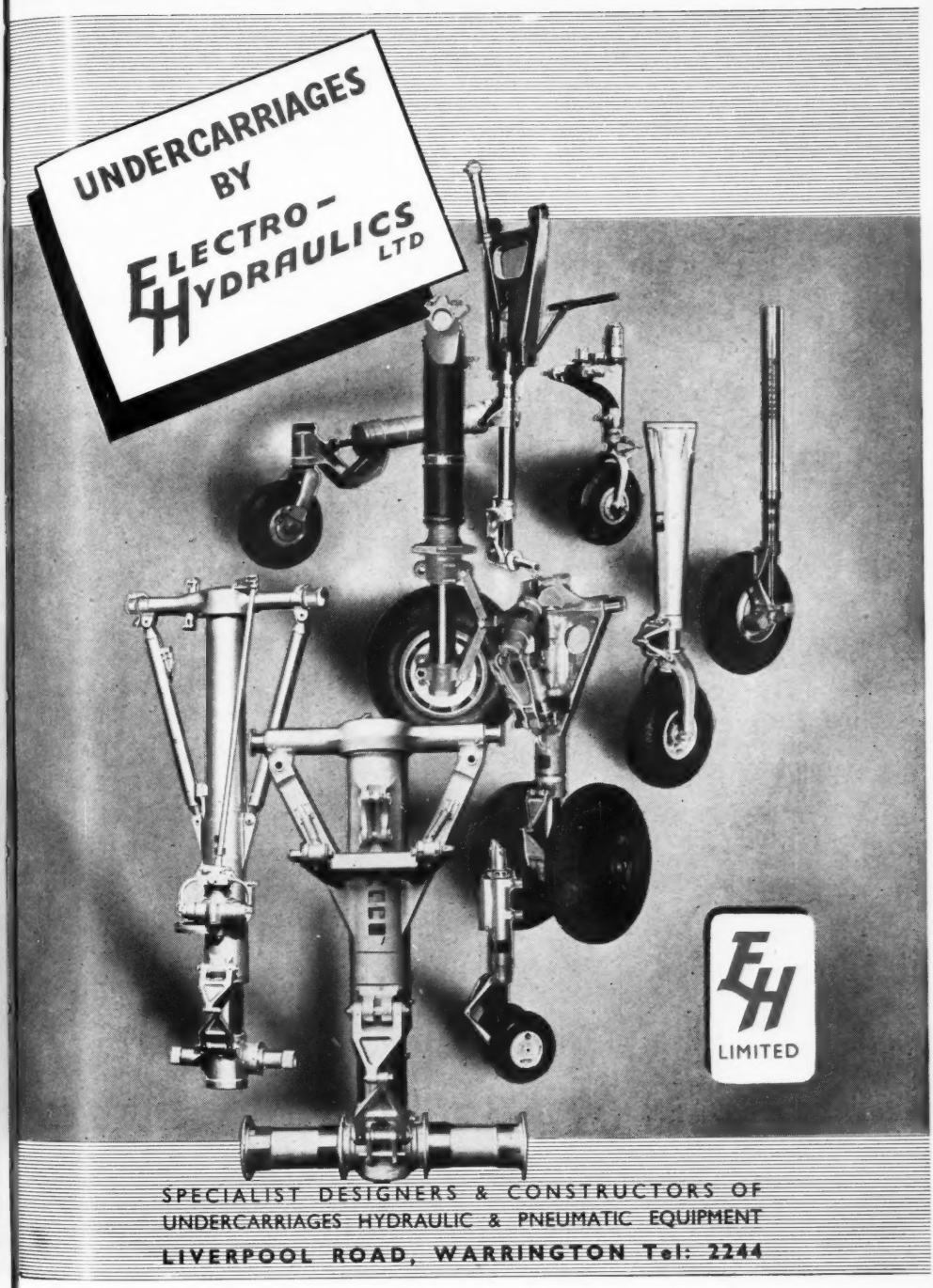
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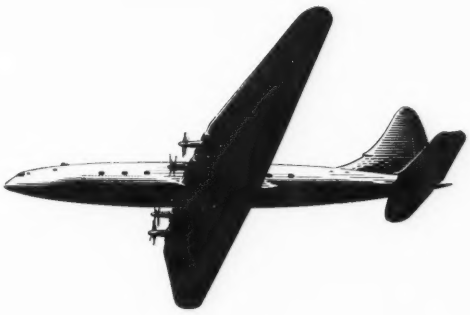

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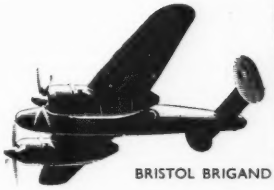

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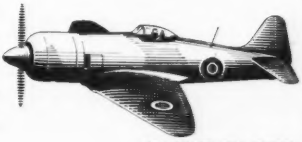

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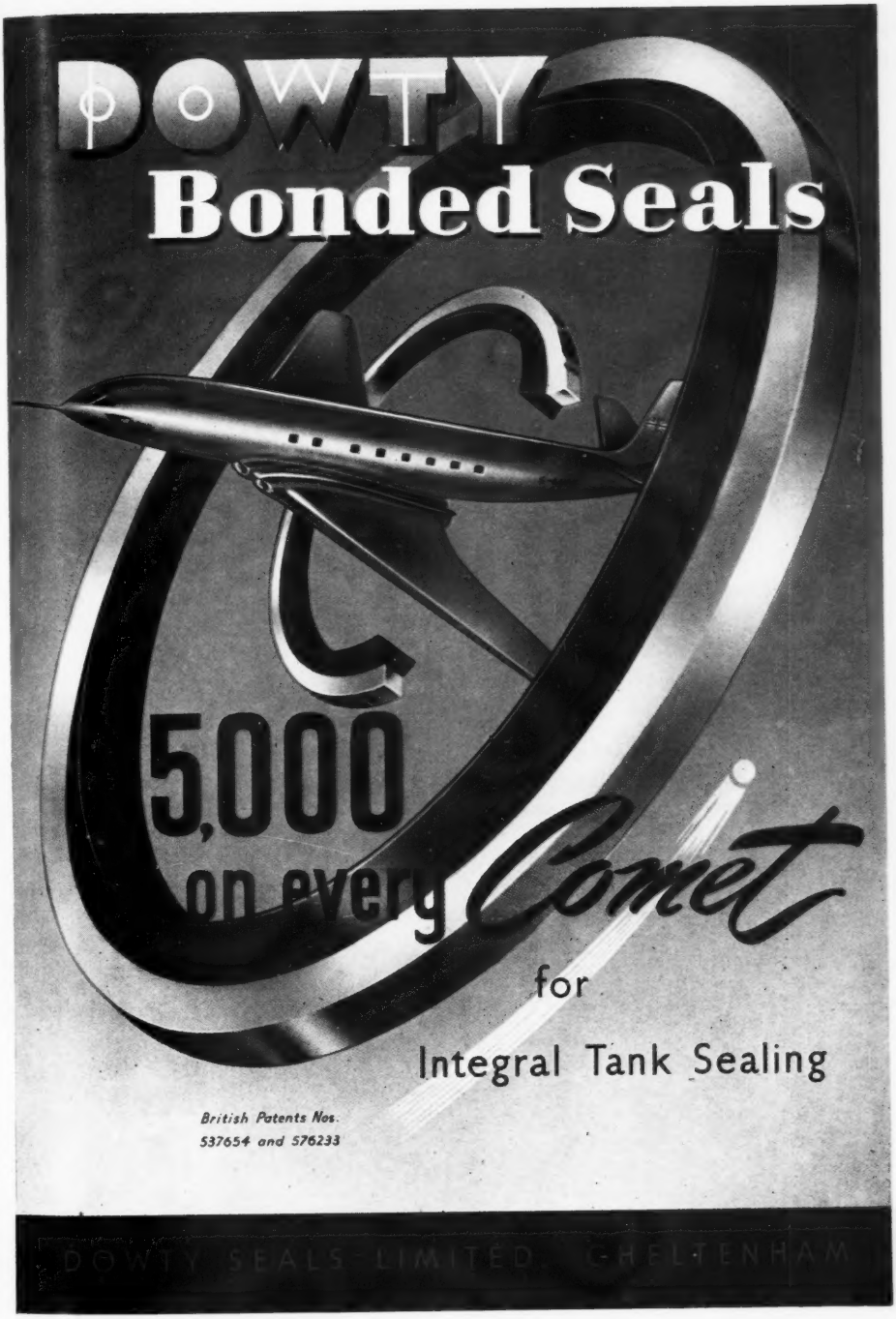
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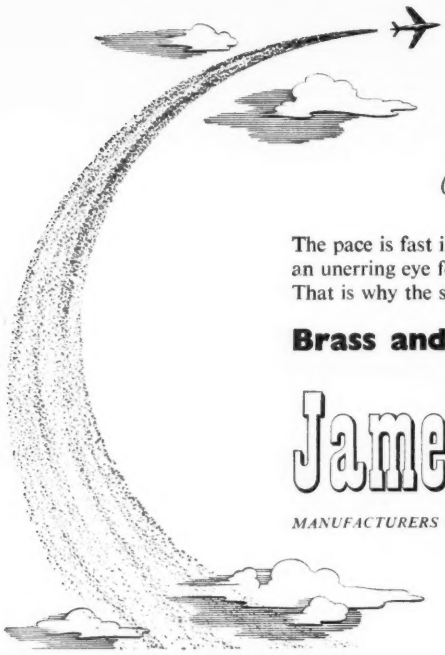

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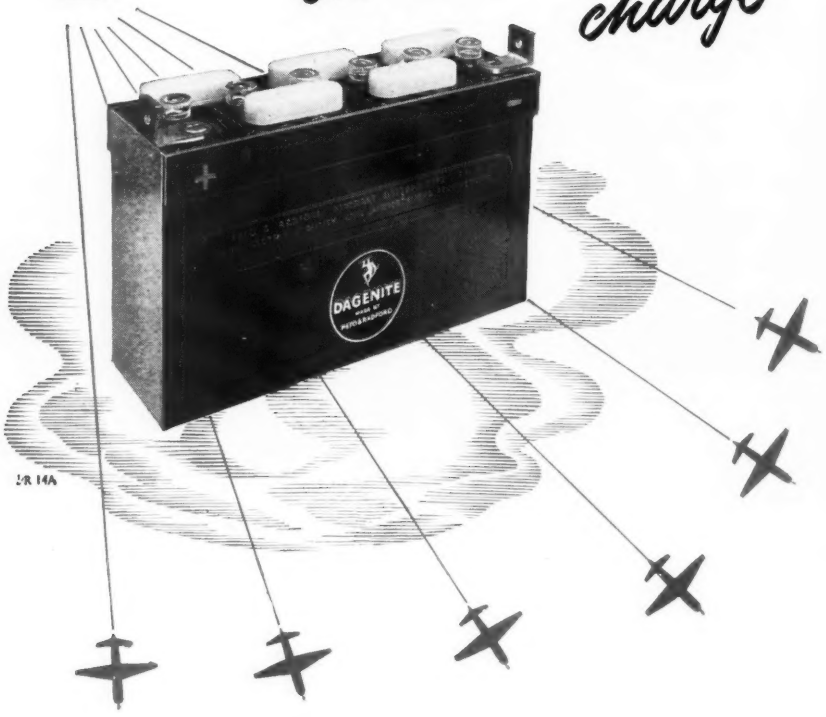

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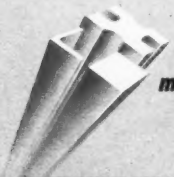

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PLANNING AND PRODUCTION METHODS USED IN THE CONSTRUCTION OF THE DE HAVILLAND COMET

by

H. POVEY, A.F.R.Ae.S

THE 825th LECTURE to be read before the Royal Aeronautical Society, "Planning and Production Methods Used in the Construction of the de Havilland Comet," by H. Povey, A.F.R.Ae.S., was given at the Institution of Civil Engineers, Great George Street, London, S.W.1, on Thursday 12th April 1951. Major G. P. Bulman, the President of the Society, presided.

Opening the meeting the President said they met that evening in the shadow of a grevious loss sustained by aviation throughout the world, and by the Society, in the unexpected death of Mr. W. G. A. Perring on 8th April through heart failure. The shock to those of them who worked with him and knew him well was still so deep that one could not try to pay an adequate tribute to his great services.

He went to Farnborough in 1925 as a Junior Technical Assistant and worked his way up, becoming Deputy to Mr. W. S. Farren during the 1939-45 War. In 1946, twenty-one years after entering the Establishment, he became its Director.

Perhaps Perring's greatest achievement was the design of the 10 ft. × 7 ft. High-Speed Tunnel, which had played such an important part in the past decade in the development of high speed flight. Much of the ground work which had enabled the remarkable high speeds to be reached by modern British aircraft had been due to the unremitting drive and "vision" of Mr. Perring.

There were few men who could equal him in the extraordinary ability that he had in so many different branches of science; and to that he added great administrative power and forcefulness of character. In fact, in recent years he had become an institution in himself and not just a personality.

Apart from his great work in directing the Farnborough Establishment with its out stations, including many thousands of staff in whom he created and maintained an astonishing degree of loyalty to their chief, he had many other activities, not least in the Society. He had been a member of Council for several years, he was Chairman of the Medals and Awards Committee, and the Technical Committee, a member of the Finance Committee and for some time a Vice-President. He was a leading member of the Aeronautical Research Council, and also of the Commonwealth Research Council, which he attended in Canada in November 1950.

His passing had left a tremendous blank.

They could not really appreciate the full depth of character and strength of a man unless they had had cause to argue with him, and the more hotly the better. With a man of Perring's strength of personality and undeviating devotion to what he thought was right, it was inevitable that many of them both officially and in council and on committee should conflict with him. But in all those arguments, quite heated sometimes, one had no question about his utter sincerity, his single mindedness, and when they had had their discussion and come to agreement, either on his or the other side, it was finished; it was entirely impersonal. So, he thought, one could say that William Perring not only lived for Farnborough, but died for it.

The President then introduced the Lecturer, Mr. H. Povey, who had been in the Aircraft Industry for about 37 years. Since 1924 he had been with the de Havilland Company and was now Director (Aircraft Production). He had organised the manufacture of the Dove, Chipmunk, Vampire, Venom and Comet.

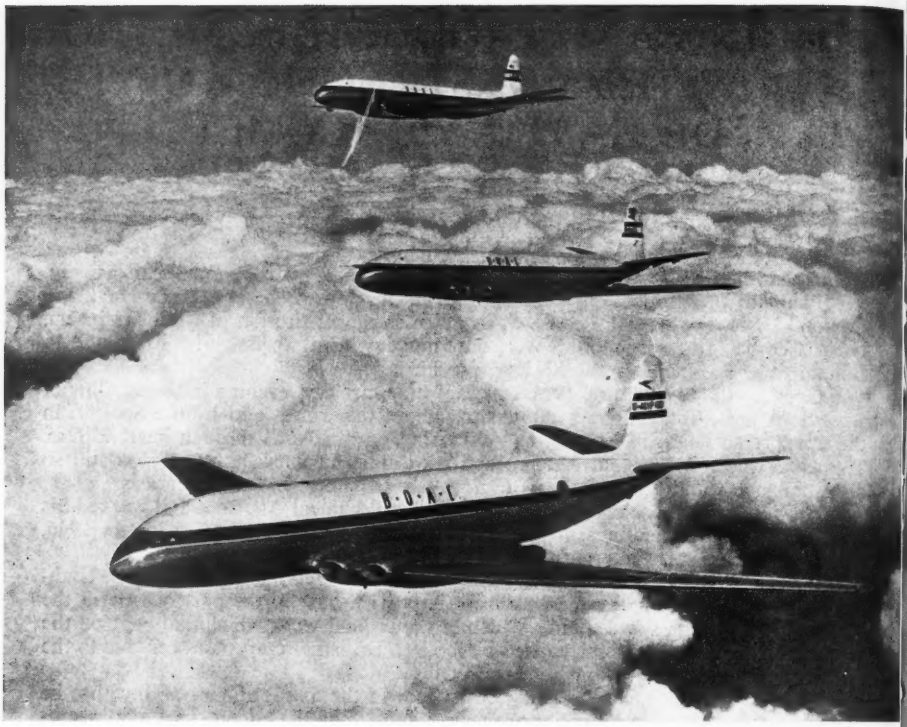


Fig. 1.
The first three Comets flying on test together, a photograph taken on the 29th March 1951. The prototype Comet flew for the first time on the 27th July 1949 and the first production Comet exactly 12 months later—on 27th July 1950.

INTRODUCTION

The problem of producing the high speed four jet-engined Comet presented the usual problems which are already well-known to production engineers. They may be defined under the following headings:—

(1) Tooling of the production batch in such a manner that it will assist and expedite the completion of the prototype aircraft.

(2) The production of a small batch of aircraft at a reasonable cost. This involves:—

(*a*) A survey of essential tooling and the production of such tools at a cost justified by the contract price.

(*b*) The production of tools within a period of time limited by the planning.

(3) The production of the tools within the time factor and to a standard which would ensure the high quality demanded by an aircraft in the category of the Comet.

(4) The first aircraft of the production batch to be made to a programme which allows only a small gap between the flying of the prototype and the flying of the first production aircraft.

(5) The development within the planned period of new processes and techniques not yet fully established.

To achieve the foregoing it was necessary to initiate a planning which needed the full co-operation of Design, Experimental, Test Laboratory, and Production Departments.

In most of the issues reasonable success has been achieved, and a brief survey of the planning and tooling methods used may be of interest.

DESIGN AND PRODUCTION LIAISON

The original plan was to fly the first production aircraft six months after the prototype had flown and, although this was not achieved, the first of the production batch of aircraft did fly exactly twelve months to the day after the prototype, and this performance was not considered a complete failure.

To see the achievement against the planned programme, the fact must be taken into account that the flying control system on the first production aircraft underwent extensive changes in design which, together with many other alterations, accounted for a delay of a few months. During this period, most of the tooling was also nearing completion.

An essential part of the planning was to establish a strong liaison between the Design team and the Production Department, particularly under heading (1) "Production tooling used to expedite the prototype."

Great importance is attached by the de Havilland Company to this design and production liaison and without it the achievement would certainly not have been possible. The author and his Chief Production Engineer attended all design progress conferences, and this enabled the production team to obtain a forward knowledge of the design requirements. It also enabled decisions to be taken at these meetings as to how best the production team could assist

Fig. 3.
The door jamb and frame, both of which involved the development of drop hammer technique and the production of heavy tools. Pressings were available for the prototype aircraft.

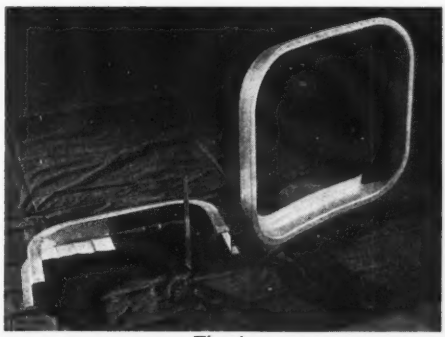


Fig. 4.
The window frames, from drop hammer pressings, were produced in the early stages of design.

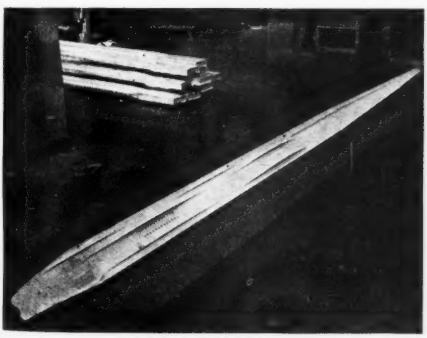


Fig. 2 (*above*).
A spar boom, fully tooled and spar milled, was available for the prototype.

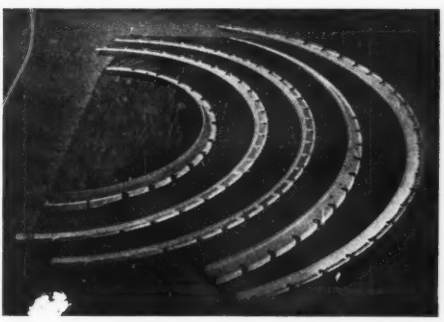


Fig. 5 (*right*).
A representative selection of fully-tooled fuselage rings which are formed and stretched on the Hufford machine. *See also* Figs. 39, 40 and 41.

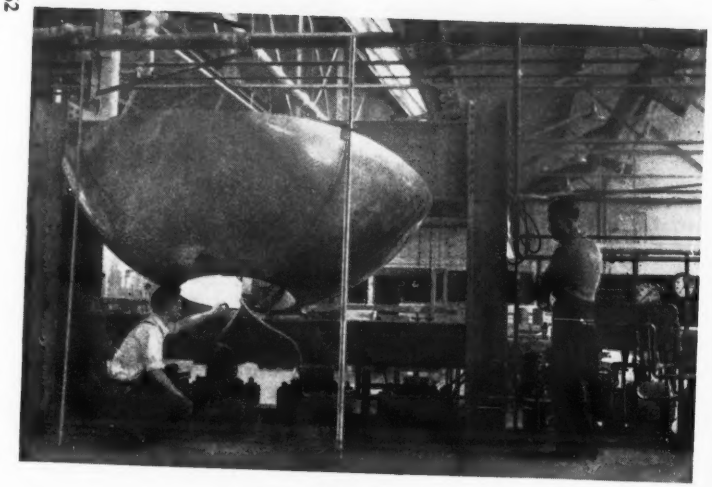


Fig. 6.
The rear pressure dome, which forms the aft limit of the pressurised section of the fuselage. The separate components are formed on the drop hammer and are shown being Reduxed together. (*See also* Fig. 47.)

Fig. 9.
Typical glass cloth mouldings developed for the first time by the de Havilland Company for use on the Comet. Their manufacture is described later in the text and illustrated in Figs. 118 to 122.

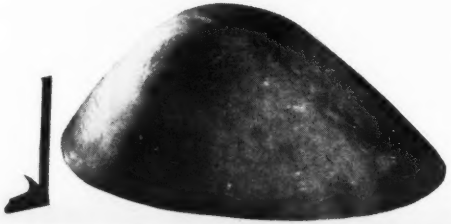


Fig. 7 (*left*).
The nose portion of the fuselage. Its depth and unsymmetrical shape necessitated the production of three-stage drop hammer tools (*see* Fig. 35).

Fig. 8 (*right*).
This flanged ring forms the attachment between the fuselage nose and the shell and involves an interesting rubber press operation (*see* Figs. 36, 37 and 38).

the Experimental Department by the early tooling of difficult parts. Such decisions were vitally important at the early stage of the design, and a complete understanding had to be reached between Design, Experimental and Production Departments. It meant that the designers must take a reasonable risk and Production must anticipate that many modifications may be needed as a result of the early decisions which have been made.

Some results of this liaison and the assistance given by Production to enable the Experimental Department to expedite the flying of the prototype are shown in Figs. 2-13. It will be obvious from these figures that it was necessary for the designers to bring forward certain stages of design which otherwise would have been left to a later date.

Figure 2 shows the spar booms which were fully tooled for spar milling from the beginning. This required a very early decision and risk by Design. Fig. 3 shows the door jamb and door frames, all of which necessitated the development of drop hammer technique and the production of heavy tools. Fig. 4 shows window frames, which were completely tooled on the drop hammer, and Fig. 5, fuselage rings, fully tooled on the Hufford machine. Fig. 6 shows the pressure dome, produced from drop hammer pressings, and the Redux method of jointing the panels which was developed.

The nose portion to the fuselage, which necessitated the production of three-stage drop hammer tools, is shown in Fig. 7.

Figure 8 shows the attachment ring between the fuselage nose and shell. The development of this tooling is interesting and will be dealt with later.

Figure 9 shows typical glass cloth mouldings which were developed by the Company for the first time on the Comet.

Figure 10 illustrates the test wing built by Production for physical test, and Fig. 11 a 24 ft. section of the fuselage used for physical test. Fig. 12 shows the prototype bogie undercarriage, and Fig. 13 the nose-wheel chassis.

To enable this early tooling to be achieved it was necessary for the designers as well as the Production Department to exert considerable effort in the early stages of the project. Although this imposed a heavy load on an already over-loaded Production Department, in the author's opinion it has paid a great dividend.

Fig. 10.

A production wing undergoing physical test in the structural test rig. Early design decisions had to be made so that tooling could go ahead and enable this and other test specimens, such as those shown in Figs. 11, 12 and 13, to be tested at an early stage.

It enables Production to gain some early experience on the type, and the operators to develop an early technique, and for the building of such large components as test wings, the early development of tooling and the elimination of snags proved a great asset to the Production Department.

The glass cloth moulding was a development by the Production Department, and to enable this to be done before designs were available, typical designs were used to make the experiments and to develop the technique.

The Redux* process on the wing skin and fuselage had already been partially developed and was in full production on the Dove aircraft. Taking a retrospective view it is now obvious that the technique used on the Dove was only in its infancy, compared with the requirements of Redux on the Comet.

As an exercise, and to enable the Production Department to develop its technique and tooling, a typical design of wing and fuselage skin was used, as shown in Figs. 14 and 15.

* Redux is a process patented by Aero Research Ltd. for bonding metal to metal by heat and pressure and to replace riveting or spot welding.

Interesting rubber press operation (see Figs. 36, 37 and 38).

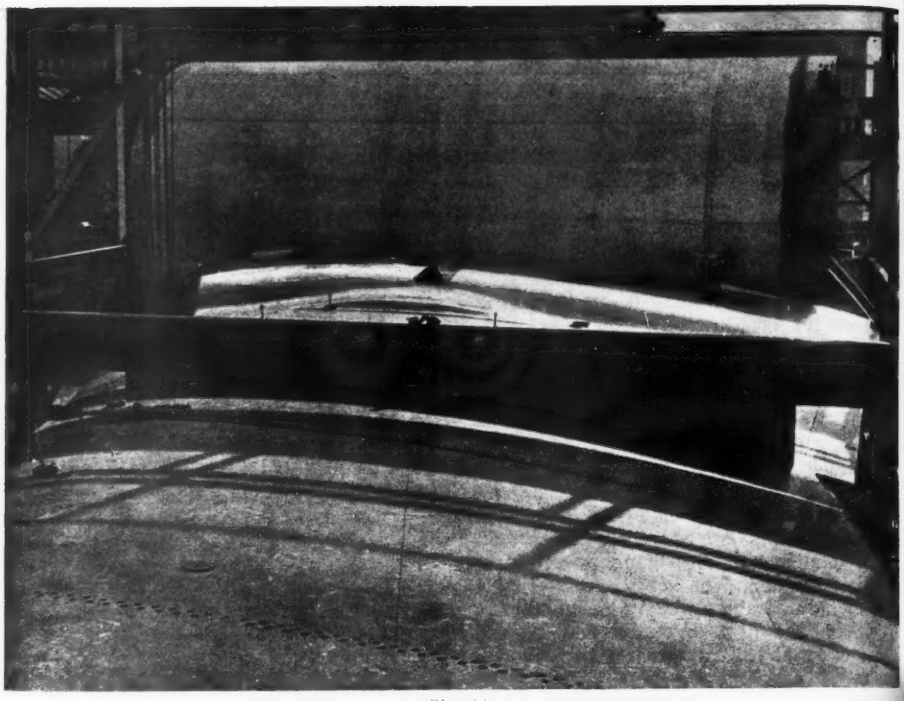


Fig. 11.

A 24-ft. section of the fuselage in position on the wing test rig. This section was first given an under-water pressure test and was then installed in the altitude chamber for the testing of the cabin air-conditioning system.

The production of these skins necessitated the design and manufacture of suitable presses. These were designed by the Company's Engineering Department and made by the Tool Section. One 35-ft. long press is used for the wing skin, and two 25-ft. long presses for the manufacture of double-curvature skins on the fuselage (Figs. 16 and 17).

As soon as the technique of producing wing skins and fuselage skins had been developed to a reasonable standard the Production Department proceeded to produce a complete wing and a 24-ft. long portion of the fuselage for physical test.

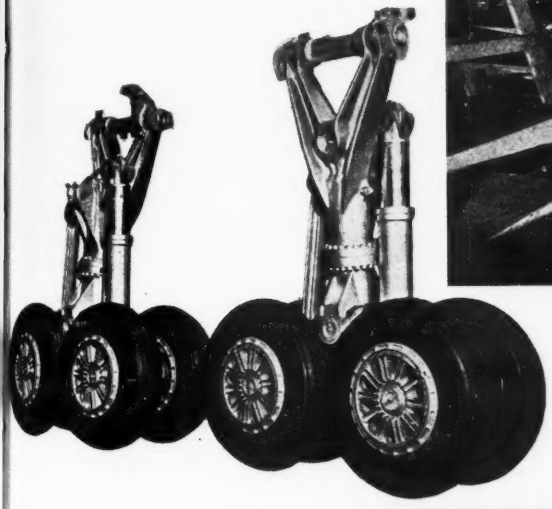
By this time, the production of tools and development had gone entirely to plan, and was working out extremely satisfactorily.

The early development of spar milling, glass cloth moulding, Reduxing of fuselage and wing skins, Hufford tools for the manufacture of fuselage rings, drop hammer tools for large components, and a complete wing-building jig, together with a substantial wing drilling jig (Fig. 18), gave the Production Department an excellent start on the first batch of aircraft.

The items dealt with under this heading of "Design and Production Liaison" should have demonstrated how strongly the

Fig. 15.

Fig. 12 (*below*).
The complete bogie undercarriage ready for installation in a production Comet. This undercarriage is de Havilland-designed and early tooling was necessary for its production. Although it was never intended that the first two aircraft should have bogies, one was temporarily fitted to the prototype for taxi-ing, take-off and landing tests.



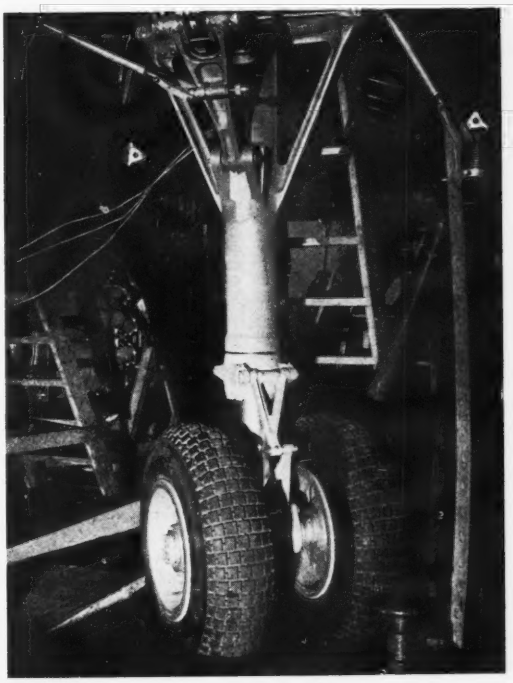


Fig. 13 (*above*).
The nose-wheel chassis.

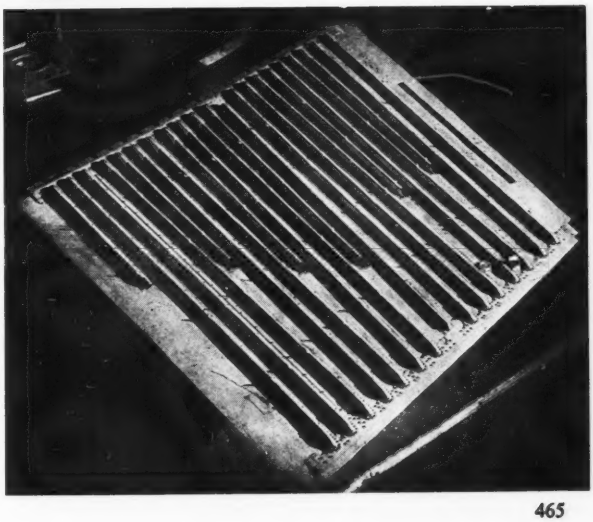


Fig. 14 (*right*) and Fig. 15 (*left*).
Two sections of typical wing and fuselage pannelling were designed and constructed to enable the Production Department to develop the technique and the tooling for the extensive Reduxing on the Comet.

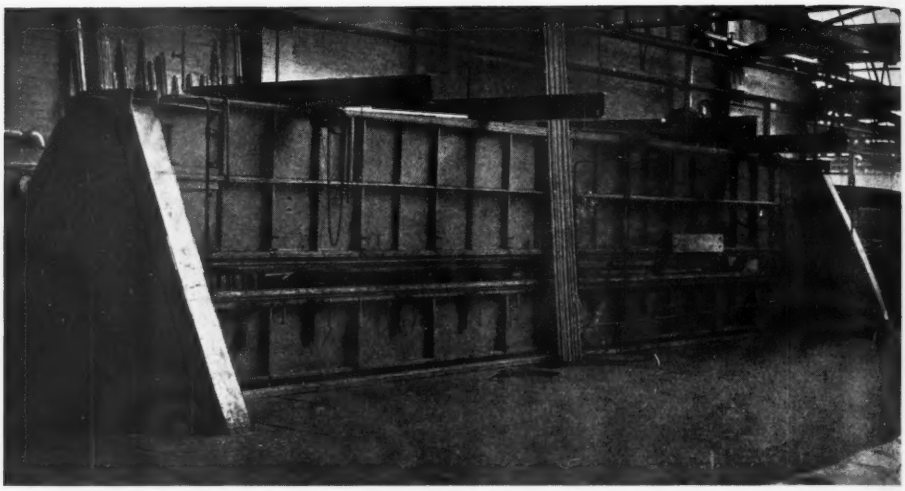


Fig. 16.
The 35-foot press which is used for the Reduxing of stringers to the wing and the fuselage panels.

Company feels that such liaison was essential to success.

Under heading (2) " Production of tools at a reasonable cost for a small batch of aircraft," a few of the methods which have been used may be of interest.

Throughout, the policy was adopted of using plaster models for the development of drop hammer, stretcher press, and Hufford tools on all major components.

The method of producing these large plaster models was to obtain from the Loft Department accurate information and loft plates. Loft plates printed on sheet metal

Fig. 18.
A view of the centre-section drilling jig showing how the well beneath the jig enables the radial drills to work from below for the drilling of root-end wing spar attachments to the centre section.

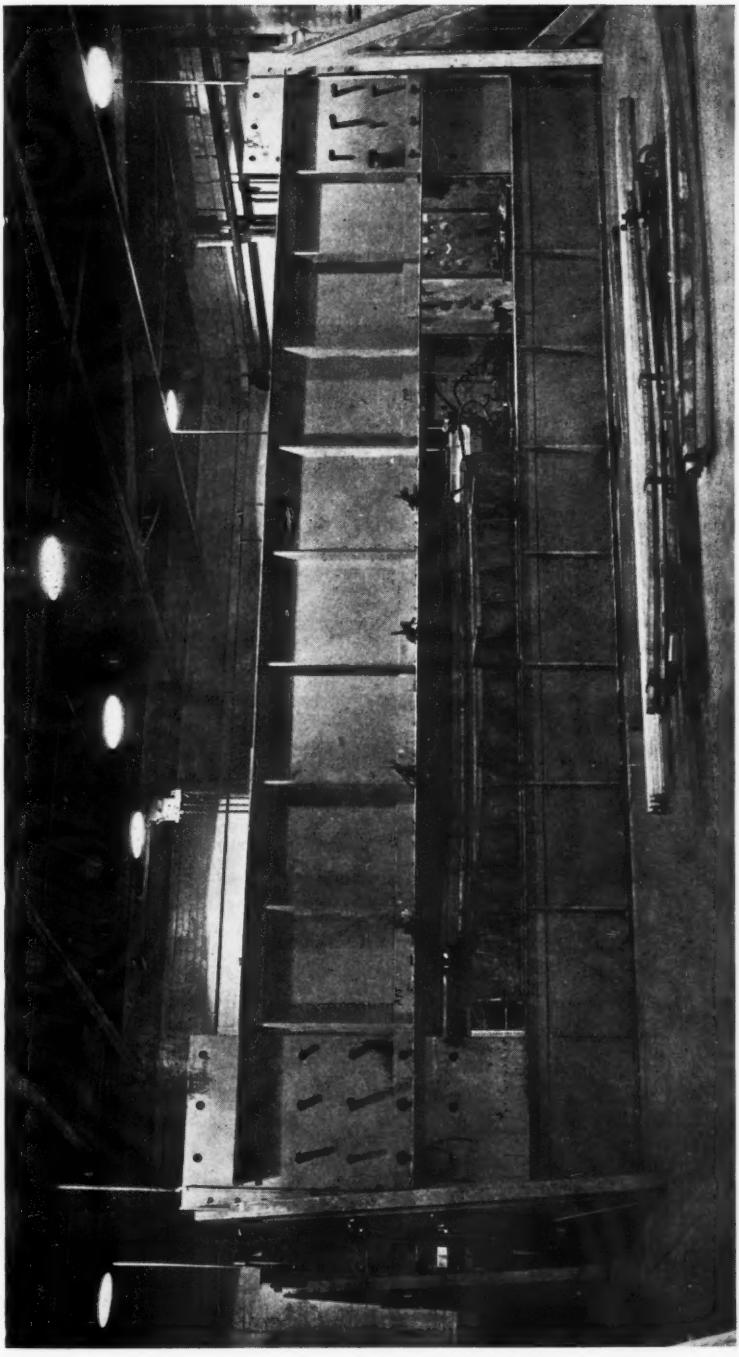
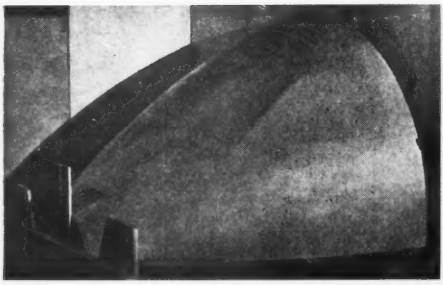
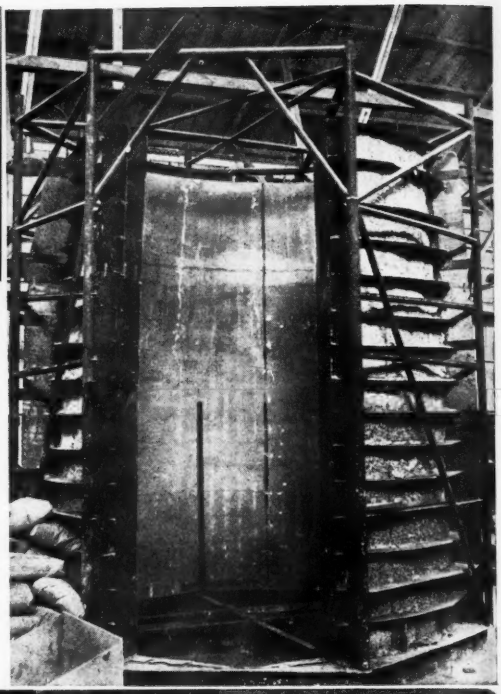
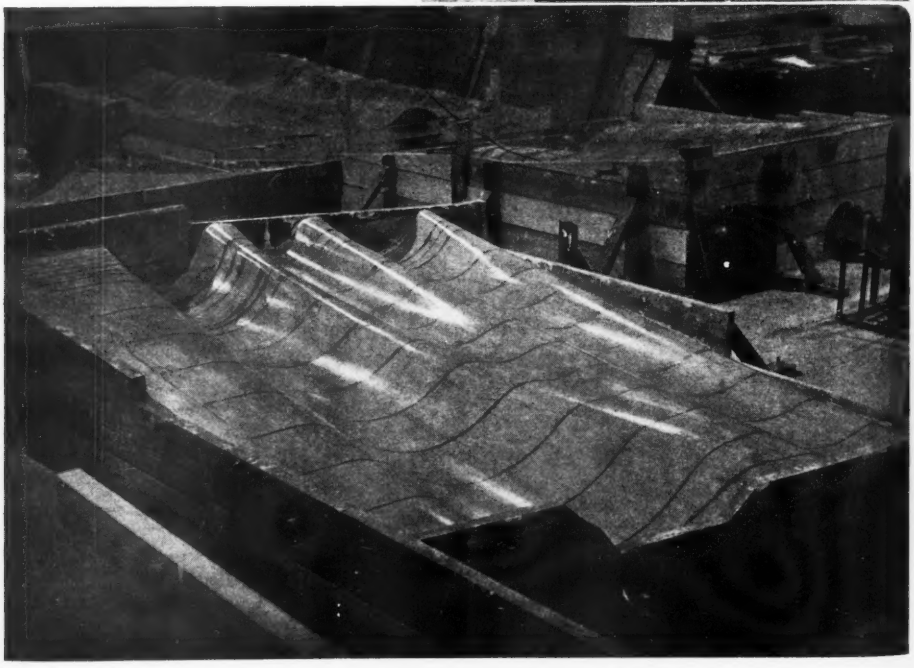


Fig. 17.
One of the two 25-ft. double-curvature Redux presses, showing a stringer being attached to a section of the fuselage skin. A close-up of the tool used in this operation is shown in Fig. 34.





Figs. 19 (*above*), 20 (*below*) and 21 (*right*). Plaster models which were used for the making of tools for the skins, stringers and frames of the canopy (Fig. 19), and the engine cowling (Fig. 20), and the rear fuselage Section (Fig. 21).



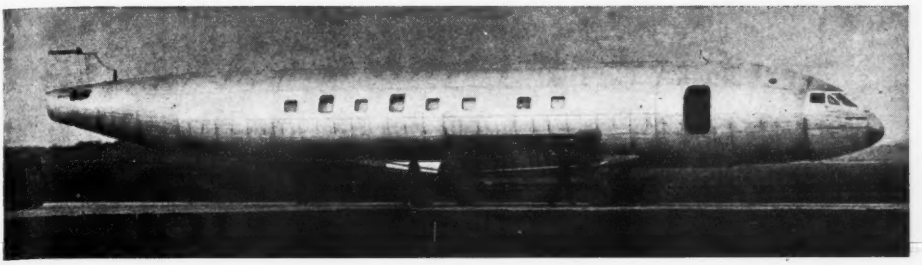


Fig. 22.
A completed fuselage, still on its centre-section trolley but with tyred wheels fitted in place of the steel castors, being towed from the fuselage shop to the assembly lines after its pressure test.

were then cut out and assembled into three-dimensional structures. These structures were then filled with plaster and they provide the accurate solid models from which the majority of the tooling is made.

Figures 19, 20 and 21 illustrate some of the finished plaster models, to which reference will be made later:—Fig. 19, the canopy; Fig. 20, engine cowling; and Fig. 21, the rear fuselage (double-curvature portion).

FUSELAGE TOOLING AND CONSTRUCTION

Only the highlights of fuselage production which the Company considers are rather unorthodox and which may be of interest have been selected, and are shown in Figs. 22-27.

Figure 22 shows the completed fuselage, and Fig. 23 the breakdown of the fuselage, showing the elements from which the final fuselage is constructed.

Figure 24 shows the forward double-curvature portion of the fuselage and Figs. 25 and 26 the start of construction of the large plaster model for the forward part of the fuselage. Fig. 27 shows the finished plaster model.

As Reduxing is one of the most advanced techniques used on the Comet, the production of stringer to skin Redux tools used for the production of double-curvature fuselage panels will be described briefly.

The fuselage nose plaster model is accurate to within a tolerance of 1/32nd inch, and contains a complete replica of the position and shape of all stringers and panels. The stringers are represented by the grooves which are formed in the plaster. The fact that in the side view the centre line of the fuselage nose structure is a curve, necessitated the production of separate left and right-hand tools for each stringer. The total number of tools produced from this model for Redux purposes only was sixty-four pairs.

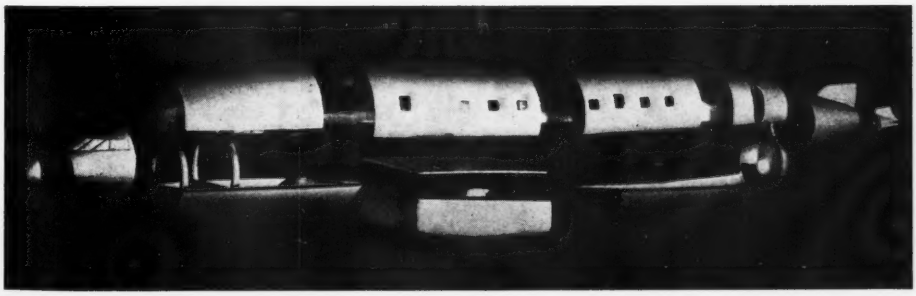
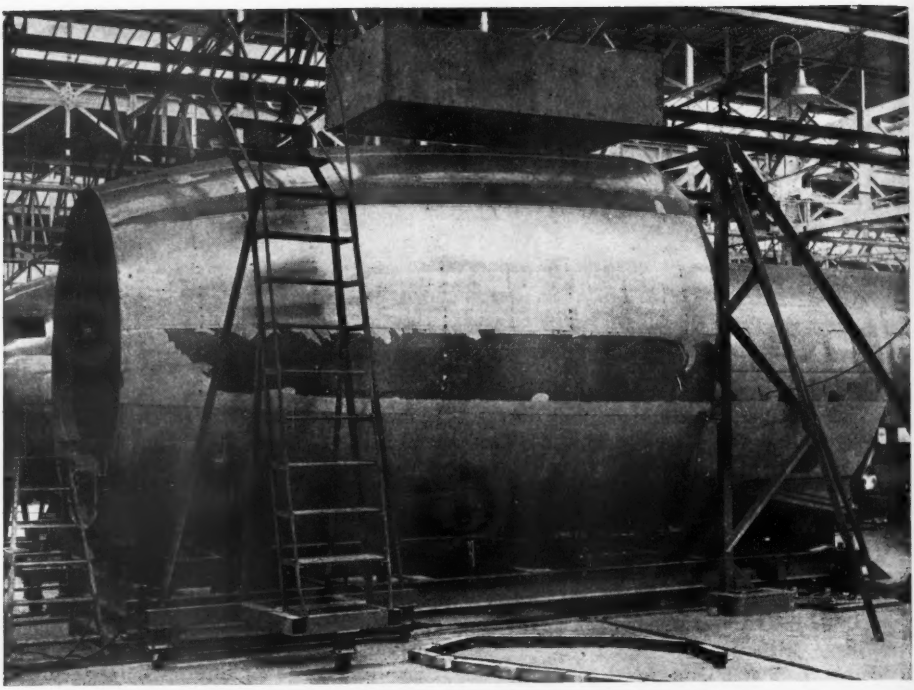


Fig. 23.
A model showing the breakdown of the fuselage into its main components. All these parts are put together on the static jig, and transferred to the mobile jigs on the production line for boxing up with the keel portions.



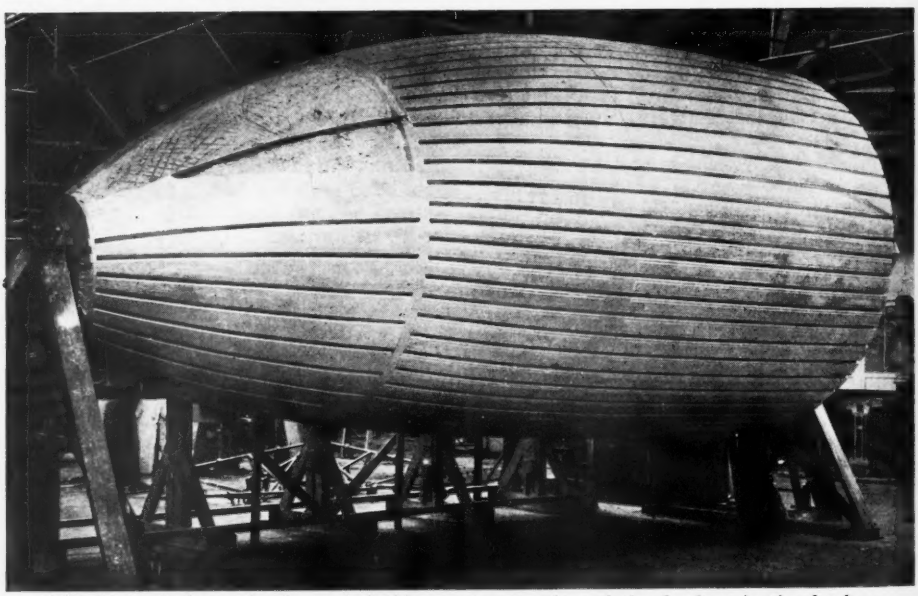
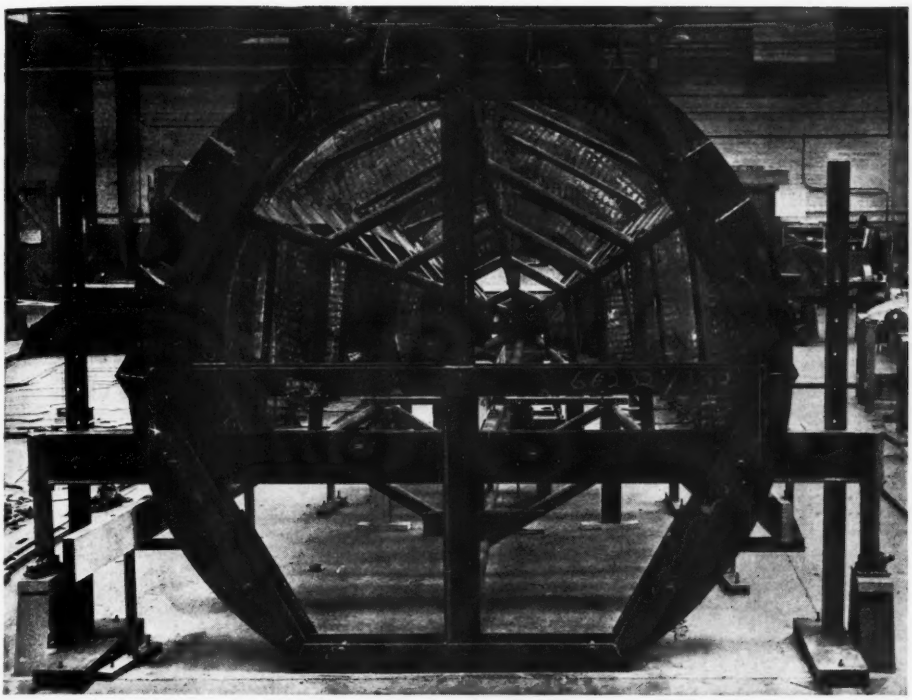
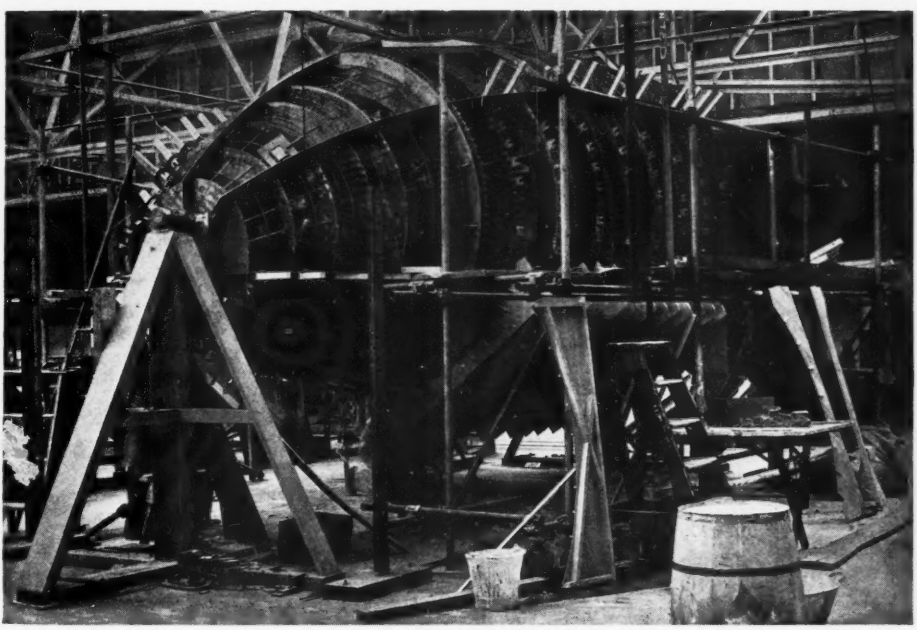


Fig. 24 (*top*) shows the forward double-curvature portion of the fuselage in the fuselage construction shop and Fig. 27 (*above*) shows the full-scale plaster model used for making the forward part of the fuselage from which sixty-four pairs of tools were produced for Redux purposes alone.





Figs. 25 and 26.
Early stages in the construction of the full-scale plaster model shown in Fig. 27 (*opposite*).

The Redux process consists of applying heat and pressure by suitable tools to the parts to be bonded together. The problem was to produce these tools accurately and at a reasonable cost.

The mating surface of the top and bottom tools had to be a one hundred per cent. perfect fit, as it is essential that every part of the surface for which adhesion is required must have equal pressure. The form of tool used is shown in cross section in Fig. 28. This tool is a composite unit and comprises top and bottom pressure bars with loose cappings fitted to each. The main pressure bars are made from hollow duralumin extrusions, which enables steam to be supplied through the bore of the extrusion for heating and curing of the Redux.

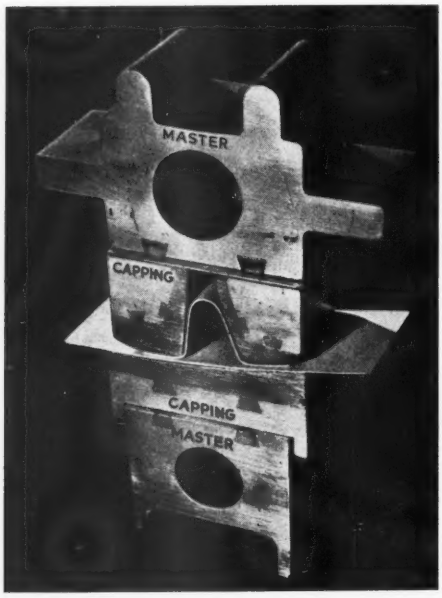


Fig. 28 (*above*).
The tool used for the Reduxing of stringers to fuselage skins. The master pressure bars are fixed permanently to the press and the capping strips only are changed for each separate stringer.

In order to economise, only one pressure bar is used, which has been made as a master by forming to the average curvature of the fuselage nose, as determined by the plaster model (Fig. 29).

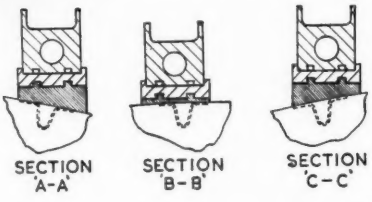
The master pressure bar is fitted with a number of loose cappings, each capping representing the double curvature of the stringer flange.

The method of producing these tools accurately and cheaply was achieved by the use of the plaster model in the following manner.

The capping is the only variant in this unit and the variation of curvature is made by casting low fusible metal on to the face of the plaster model and into the dovetail grooves in the capping. Each capping, when complete, makes a separate tool.

To produce these variations in the cast face of the capping the hollow extrusion and capping, formed as a unit (Fig. 30), is supported on an adjustable table placed adjacent to the plaster model. The nearest part of the unit is kept half an inch away from the plaster model, and is adjusted so that the ends of each extrusion are an equal amount away from the model at the two extremities, as shown in Fig. 31.

Having determined the best position for this tool in relation to the plaster model (Fig. 32) the lower extremity of the gap



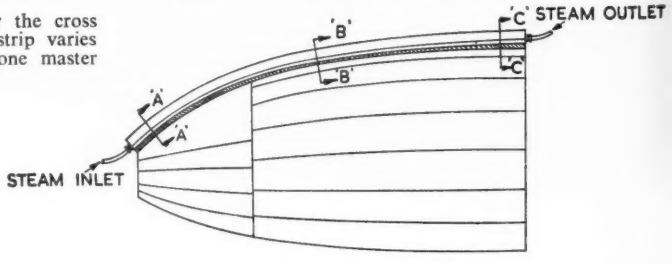


Fig. 29 (*right*).
This diagram shows how the cross section of each capping strip varies along its length. Only one master pressure bar is used in the stringer-to-skin Reduxing operation. The method employed for casting the capping strips of the Reduxing tool is shown in detail in Figs. 32 and 33.

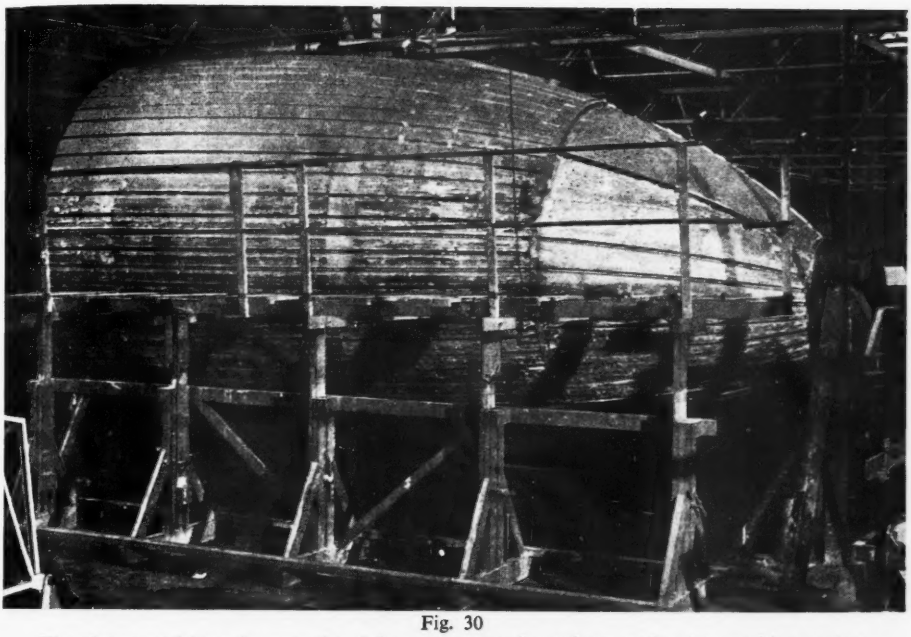


Fig. 30

The plaster model can be rotated to bring each successive stringer station into position against the adjustable table used for casting stringer Reduxing tools. (*See also* Figs. 31, 32 and 33.)

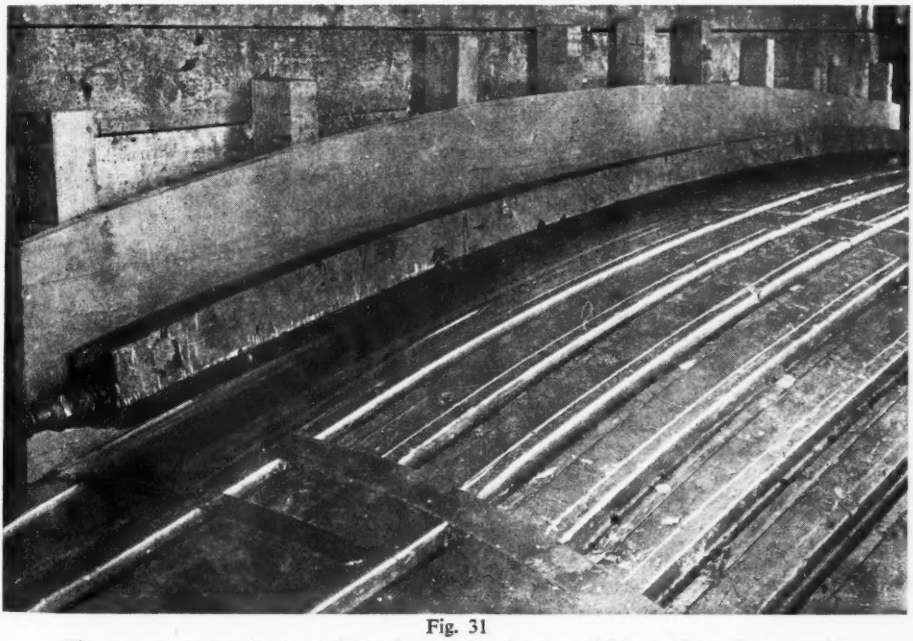


Fig. 31

The master pressure bar in position close to the plaster model in readiness for a capping to be cast.

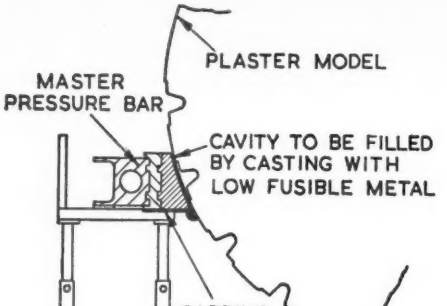


Fig. 32.

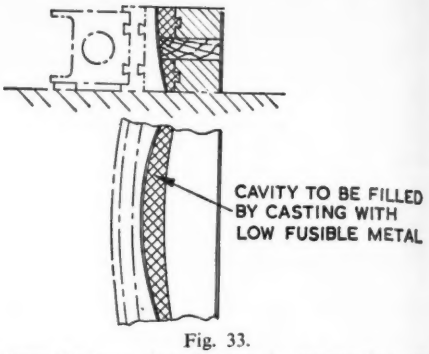


Fig. 33.

These diagrams show how each pressure bar was cast direct from the capping strip, which in turn was cast from a plaster model.

formed between the plaster and the tool is filled with fire clay on a plywood support. By this means a cavity has been formed between the plaster and extrusion. This cavity is then filled by casting with a low fusible metal which keys itself into the dovetails which are part of the capping extrusion, as previously mentioned. When cooled and set, the unit is then taken away from the plaster model and an accurate cast face

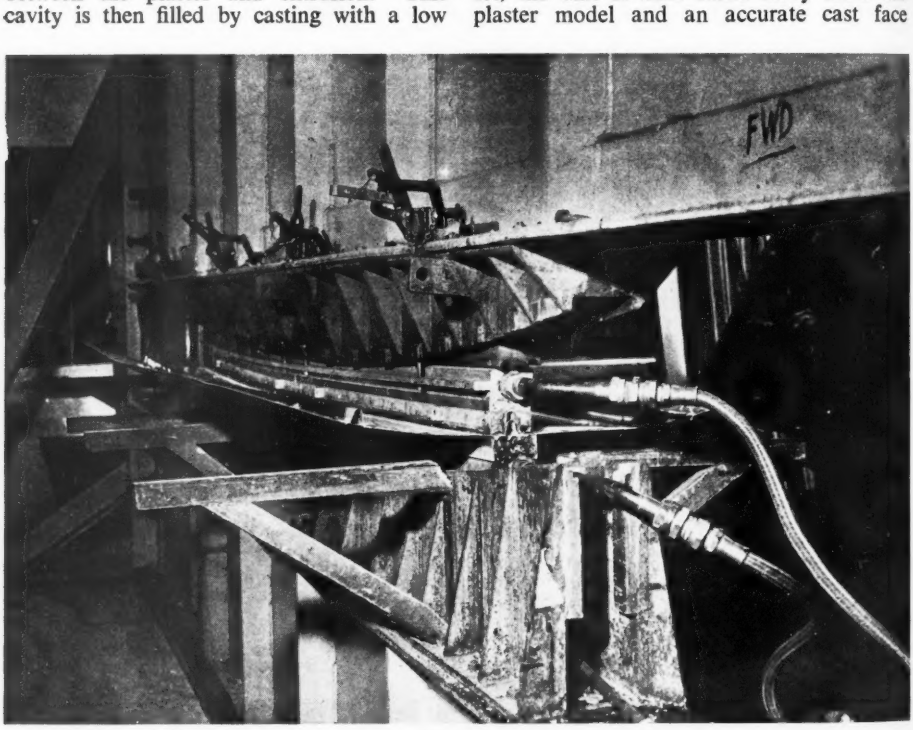


Fig. 34.

A stringer being Reduxed to a section of the double-curvature fuselage skin. The method of supplying steam to the master pressure bars for the heating and curing of the Redux can be seen. The capping strip for each individual stringer can be changed easily.

representing the stringer flange has been obtained on the capping.

Because the tools, when in operation, are at a temperature of 140°C. and therefore change their shape, it is necessary to heat the extrusion prior to, and during, the casting operation of the low fusible metal. This ensures that the same shape is obtained during casting as when in operation in the press.

This heat is applied when the tool is in position for casting and is obtained by steam at a controlled pressure through the bore of the extrusion.

The tool is completed by the production of pressure bars (Fig. 33) which must make a perfect contact with the face of the tool which was produced by casting on the plaster model.

The pressure bars are made by supporting the tool on a table, re-heating, and casting the mating face of the pressure bar right on to the previously formed face on the capping strip, using a parting compound of graphite. By this means the Company was able to produce a separate stringer Redux tool on each capping, the faces of which were dead accurate to the plaster model, and which needed only a small amount of fettling to make them perfect.

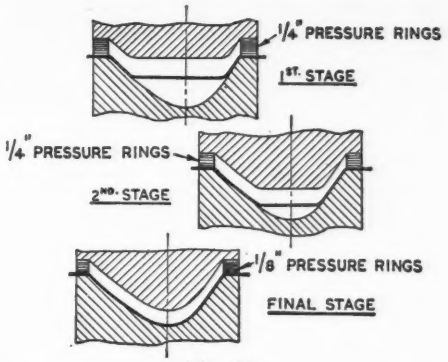


Fig. 35.

A diagram showing clearly the three stages used in the manufacture of the fuselage nose (*see* Fig. 7) on the drop hammer.

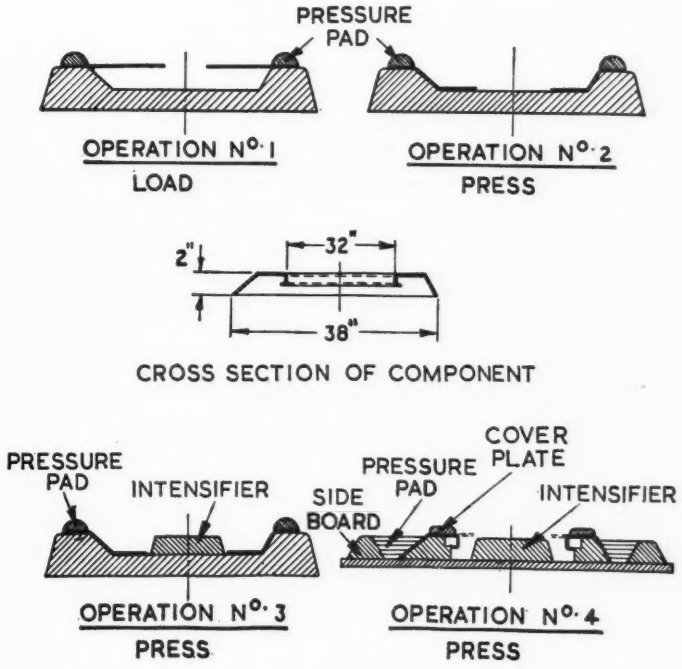
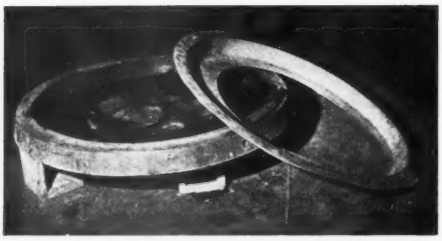


Fig. 36.

A diagram of one of the best rubber press achievements of Comet production—the method of producing the fuselage nose attachment ring shown in Figs. 37 and 38.



Figs. 37 (*left*) and 38 (*right*).
The rubber press tools used in the production of the fuselage nose attachment ring, showing the process in its third and final stages. *See also* Fig. 36.

These tools are easily set up in the presses and steam is supplied to the top tool and hydraulic pressure to the bottom tools. Fig. 34 shows the tools set up in the press.

The whole of the Redux tools for all double-curvature parts have been produced at a relatively low cost by this method.

The deep-drawn fuselage nose (*see* Fig. 7) is made of DTD.610 and although this may be regarded as an orthodox drop hammer pressing, the method used may be of interest.

The nose is unsymmetrical in shape and the depth to be drawn from a flat sheet is fifteen inches. The draw is made in three operations, as shown diagrammatically in Fig. 35. The only change of tools during the three operations is the top punch, as shown in the diagram.

The ring attachment between this nose and the main fuselage is one of the best rubber press achievements. The ring, approximately 38 inches in diameter, of variable contour and bevel with a returned edge on the centre diameter, is made completely on the rubber press in two operations. The problem was to produce the outer face without wrinkling or ripples.

This was made possible by making the initial drawing a tension operation, instead of using the more conventional method of compressing the material over the top of the tool. These operations are shown diagrammatically in Fig. 36, and the tools in Figs. 37 and 38.

The method of making the main fuselage rings is, the Company believes, the first time such a technique has been used in Great Britain.

Normally, rings of this nature have been formed on special equipment such as the geodetic machine used by Vickers, or the Avro special ring rolling mill. No such machine was available for the Comet, and even if it had been it is doubtful if a section of such thin gauge with a web the depth of three-and-a-half inches could have been formed without ripples on the surface of the flat web.

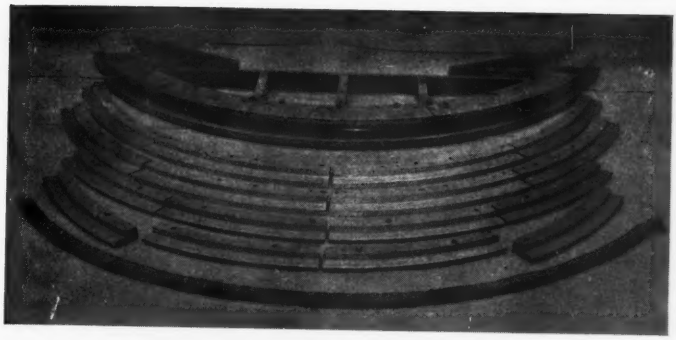
The method adopted was to produce the straight sections in a set of standard rolls. These straight sections were then formed by stretching and bending the fuselage rings of varying radii on the A.10 Hufford machine. Economy was exercised by producing one basic tool which, by adding different radii segments, adjusted the tool to all diameters of rings (Fig. 39). Figs. 40 and 41 show the tool in operation on the A.10 Hufford.

These rings are bent around the tool while under tension. By this means all buckling of the web is avoided and the webs of these 20 SWG ten feet three inches diameter rings are perfectly flat.

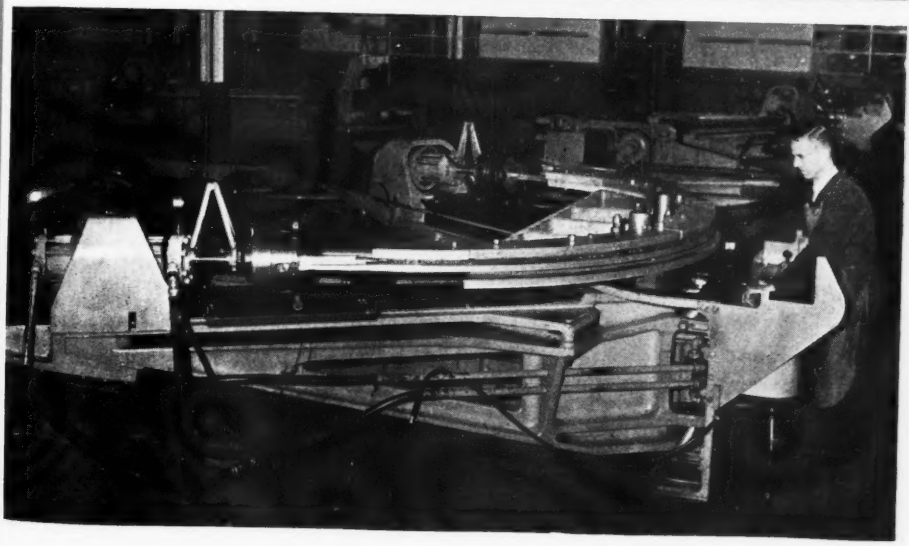
Another good production job on the A.10 Hufford machine is the manufacture of the main bulkhead, shown in Fig. 42. Fig. 43 shows the build up of the structure.

A composite tool was designed, as shown in Fig. 44, on which each element of the unit is formed. This is a particularly interesting job as the formation of each element on the same tool ensures a perfect fit of the mating faces, and as these faces have a variable camber which is stretched into each component in strict relation to each other, all assembly difficulties are overcome. All that needs to be done after the elements have been pulled on the Hufford machine is to rivet them together in a jig and the unit is complete.

Figures 45 and 46 show the Hufford tool used for the forming of the large extrusion required for coupling the pressure dome to the fuselage. Fig. 47 shows the complete pressure dome, which is a light Reduxed



Figs. 39, 40 and 41. For the forming of the fuselage frames one basic tool was used on the Hufford stretching machine, and differing radii were achieved by the use of varying segments, as shown in Fig. 39 (*above*), Fig. 40 (*right*), and Fig. 41 (*below*). The finished frames are shown in Fig. 5 (page 461).



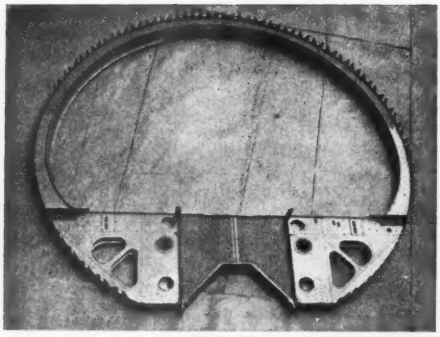


Fig. 42.
The completed main fuselage bulkhead whose various components are formed on the tool shown in Fig. 44.

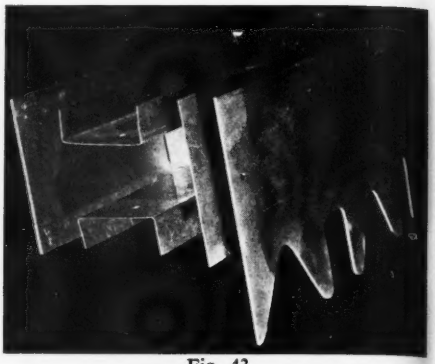


Fig. 43.
A close-up of a section through the main fuselage bulkhead showing the way in which it is built up.

structure, with the extrusion shown in position.

Components

The components are made in the simplified fuselage building jigs. The keynote for the design of these jigs was as follows:—

(1) Low cost and simplicity.

(2) Easy access for the operator for all work.

(3) Ease of movement for large components and the elimination of man-handling.

Under heading (3) a simple track was devised and once the sub-assemblies which form the breakdown of the completed fuselage are received on the track, they pass from operation to operation and eventually become a complete fuselage without any further man-handling.

All track jigs are mobile and the various components made on them can be transported to any station on the track and be built up unit by unit until the fuselage is complete.

To feed the track a number of components have to be made in static jigs and these are the only components which are man-handled

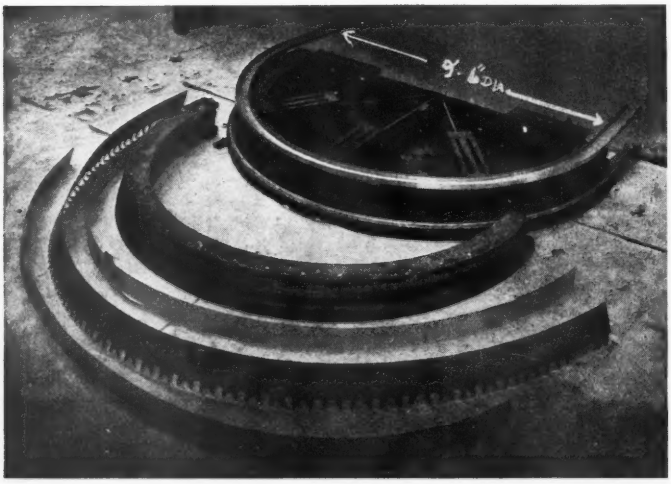


Fig. 44.
The construction of the main bulkhead (Figs. 42 and 43). A composite tool was designed which produces each element and therefore ensures a perfect fit of all the mating faces.

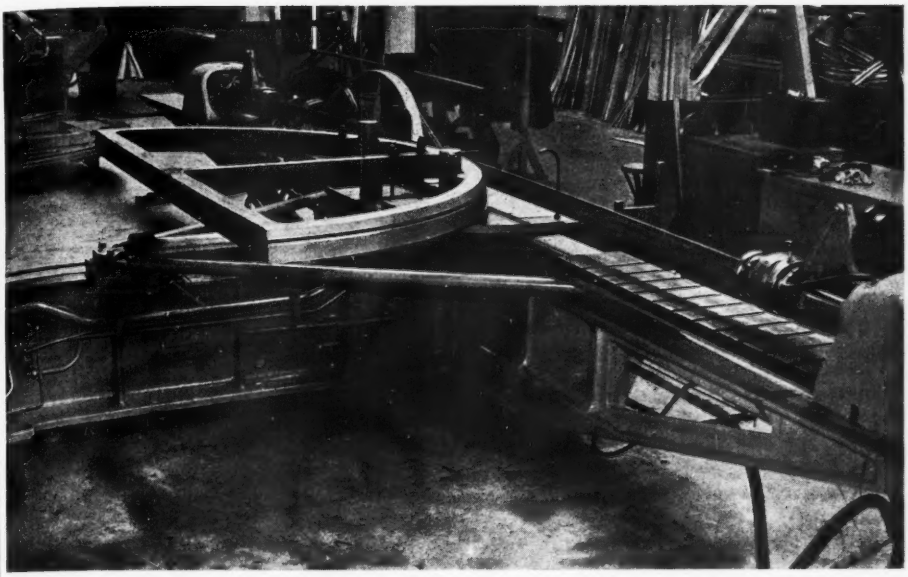


Fig. 45

on to the track trolleys at the head of the line. The components manufactured in the static jigs consist of the fuselage nose, canopy, forward section of fuselage, centre section and pressure floor, fuselage sides, front keel, rear keel, rear fuselage sides, rear cone, and pressure dome.

The battery of jigs used for the manufacture of these components is shown in Fig. 48.

The method of attaching window frames to the fuselage skin is perhaps novel as these window frames, which are deep drawn drop hammer pressings, are Reduxed to the fuselage skins *in situ* while the skin is being assembled in the fuselage side jig.

Figs. 45 (*above*) and 46 (*right*).
The extrusions shown in section in the small cross-section view in the right hand top corner of Fig. 46 (*right*) is formed on the A10 Hufford machine. This is then stretched under tension around the cast Remak tools as shown in Figs. 45 and 46.

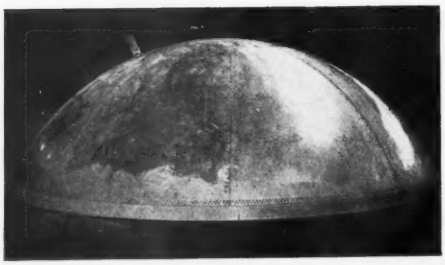


Fig. 47.

The completed rear fuselage pressure dome (*see also* Fig. 6), with its extruded attachment ring in position.

Fig. 49.

Fig. 49 (*top right*) shows a cabin window frame which has just been Reduxed to the fuselage side by the portable Reduxing apparatus shown in Fig. 50.

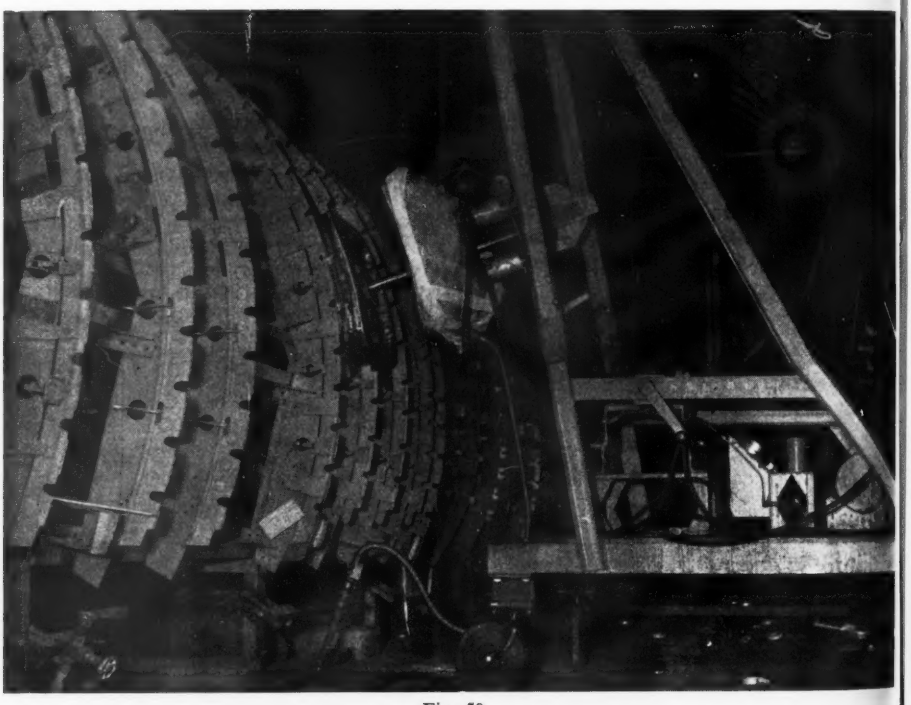


Fig. 50

The window frames (Fig. 49) are Reduxed to the fuselage skin during the assembly process on the static jig (Fig. 48). Two castings are used, one located in the jig at the window positions, and the other, a mating jig, which also forms a steam box for applying the necessary temperature for Reduxing. Pressure is applied to the mating jig by means of two Mosquito flapjacks and the operation takes about 25 minutes.

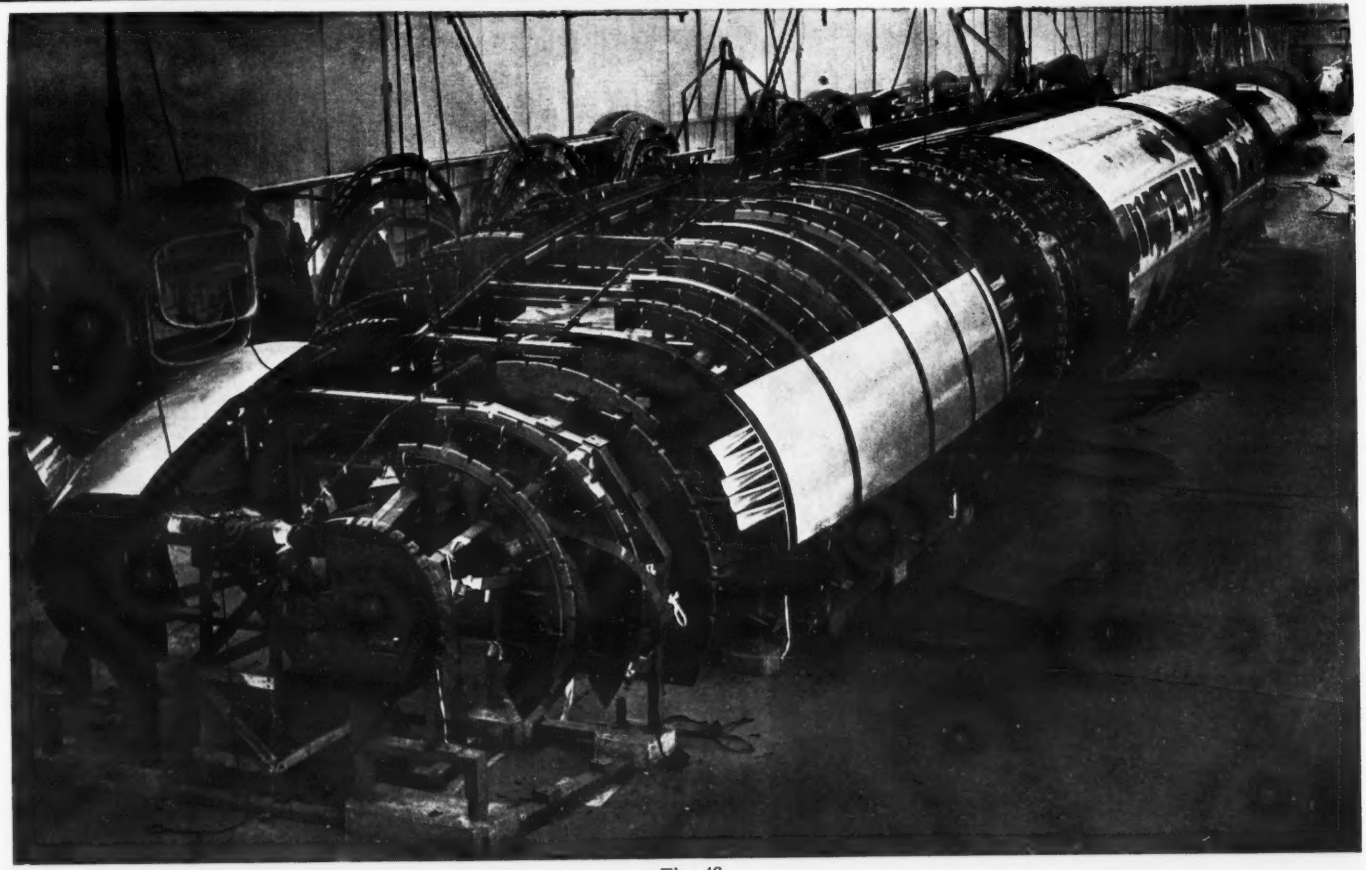


Fig. 48.

The static jigs used for the assembly of some of the larger fuselage components. This battery of jigs is designed to combine simplicity with ease of access. From these jigs the assembled components are man-handled to the mobile jigs on the assembly tracks.

Fig. 47.

The completed rear fuselage pressure dome (*see also* Fig. 6), with its extruded attachment ring in position.

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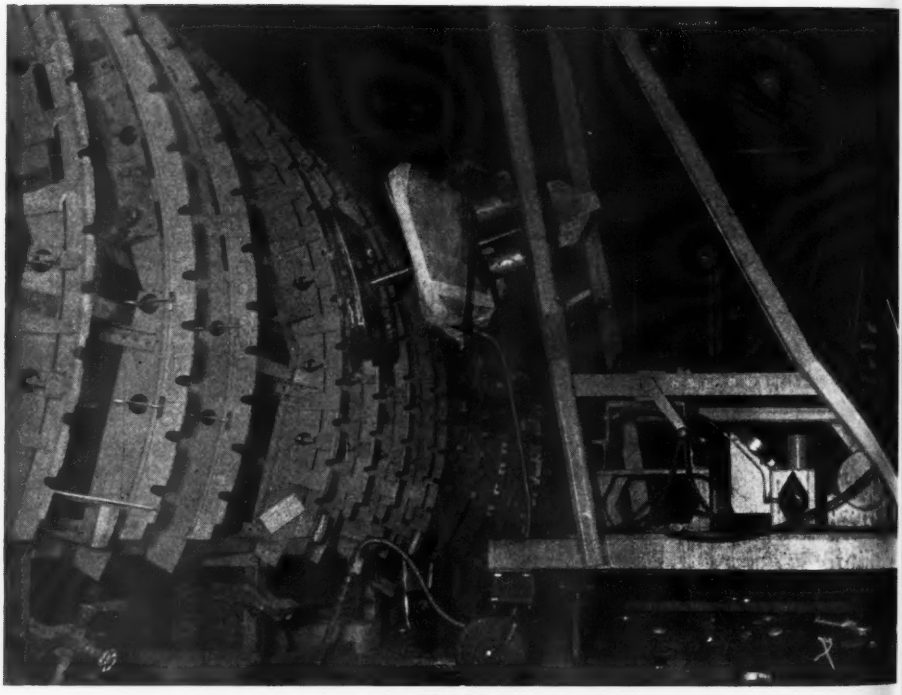


Fig. 50

The window frames (Fig. 49) are Reduxed to the fuselage skin during the assembly process on the static jig (Fig. 48). Two castings are used, one located in the jig at the window positions, and the other, a mating jig, which also forms a steam box for applying the necessary temperature for Reduxing. Pressure is applied to the mating jig by means of two Mosquito flapjacks and the operation takes about 25 minutes.

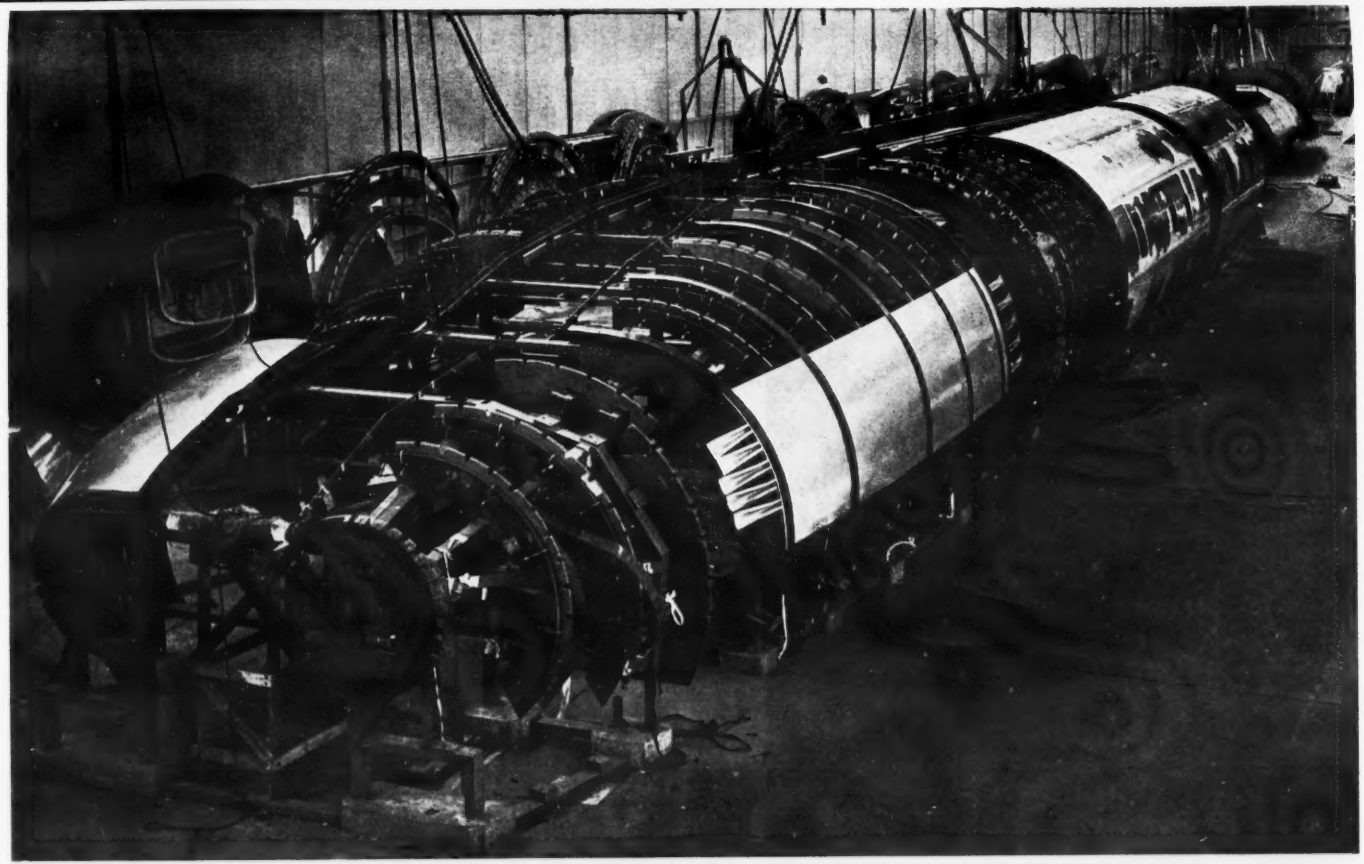


Fig. 48.

The static jigs used for the assembly of some of the larger fuselage components. This battery of jigs is designed to combine simplicity with ease of access. From these jigs the assembled components are man-handled to the mobile jigs on the assembly tracks.

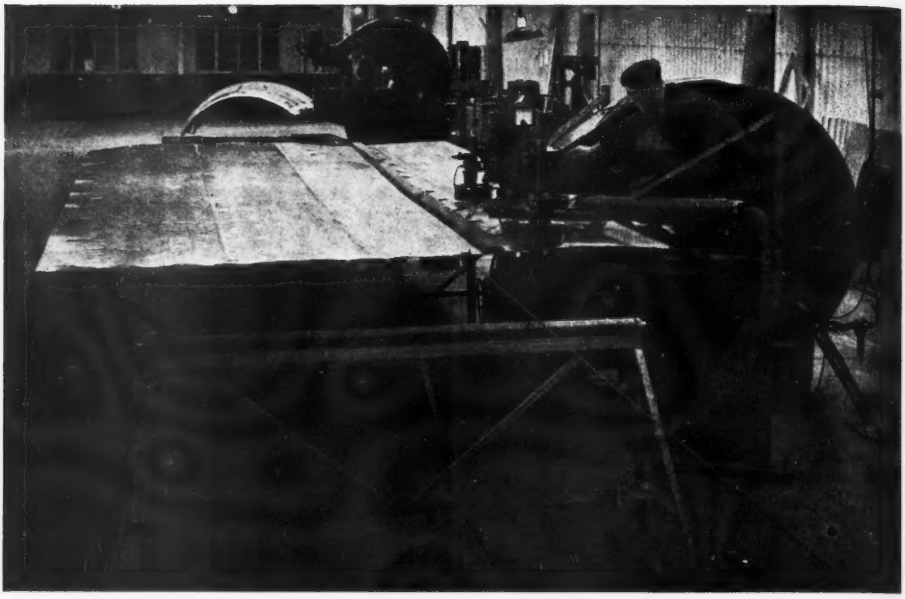


Fig. 51.
Another view of the Erco riveting machine (Fig. 52) showing that the machine has been adapted to deal with panels of unlimited size.

The equipment used for this operation is shown in Figs. 49 and 50. It consists of two castings; one is located accurately in the side jig and determines the position of the window frames, while the mating casting is a hollow casting which forms a steam box and is drawn into position by two standard four-inch Mosquito hydraulic flap jacks, which apply the necessary pressure for Reduxing. The steam which supplies the heat is obtained from a pipe which is located over the top of the jig. The exhaust passes out through steam traps at the base of the jig. Fluid pressure to the jacks is supplied by an obsolete Mosquito-type hand pump. The whole of the apparatus is mounted on a

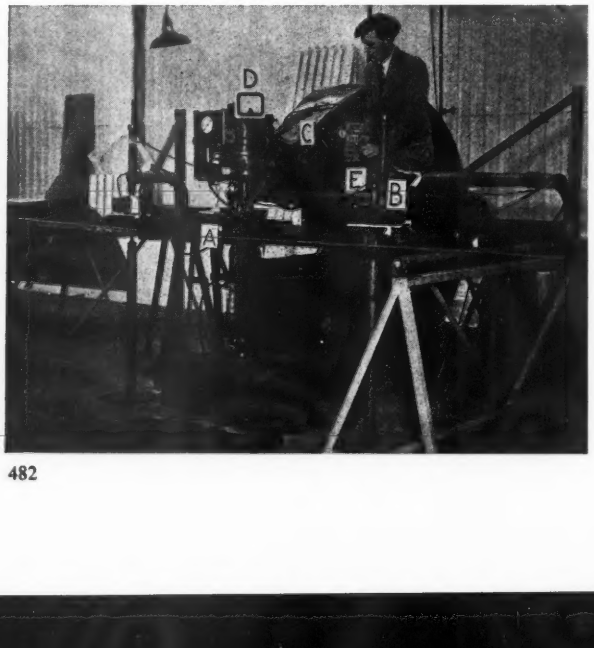


Fig. 52.
To rivet together the large panels which make up the fuselage sides a standard Erco riveting machine is used, modified in the following way to enable unusually large riveting processes to be done. A—the support for the panel to prevent its weight loading the riveting head of the machine; B—magnetic clamps to hold the panel securely throughout the punching, dimpling and riveting operations; C—a hand control to allow the operator to move the panel one pitch at a time if required; D—electronic pitch controller; E—hand-operated control to enable the operator to work the machine by remote control of the normal foot pedals.

trolley which can be wheeled into position on the jig at any station required.

The operation for fixing a window completely is accomplished in approximately twenty-five minutes.

After the Redux operation has been completed, the outer tool is withdrawn, but the inner one is left in position to locate a router template which enables a simple hand routering operation to be performed which removes surplus metal from the window orifice and when completed, gives the exact shape and position required.

The fuselage side panels consist of four skins, thirty inches wide and twenty-two feet long, on to which all stringers are Reduxed. The panels are then formed into one large skin by riveted lapped joints on the three internal edges of the four panels.

This joint is riveted together by two single rows of countersunk rivets with dimpled skins and staggered pitch. This is performed on a standard Erco automatic dimple and rivet machine modified by special adaptors to cater for the weight of this large panel. The panel itself measures ten feet two inches by twenty-two feet when completed. Fig. 51 shows the panel on the Erco in operation. Fig. 52 shows the Erco modified to enable this large job of riveting to be performed.

The modification to the Erco consists of:—

(*a*) The method of supporting the heavy panels during riveting so that the panels are perfectly flexible and no undue load due to the weight of the panel is placed on the riveting head of the machine.

(*b*) Magnetic clamps which securely hold the panel and prevent vibration during the period of punching, dimpling, and riveting, but release the panel immediately the operation is completed. This allows the panel to be transferred to the next pitch for subsequent riveting operations.

(*c*) A hand control adaptation which enables the operator to move the panel one pitch at a time as desired.

(*d*) Method of controlling the pitch of the rivets by electronic cell.

(*e*) Hand operated control instead of foot pedals, which enables the operator to function the machine by remote control to the normal foot pedals. The foot pedals are operated by solenoids.

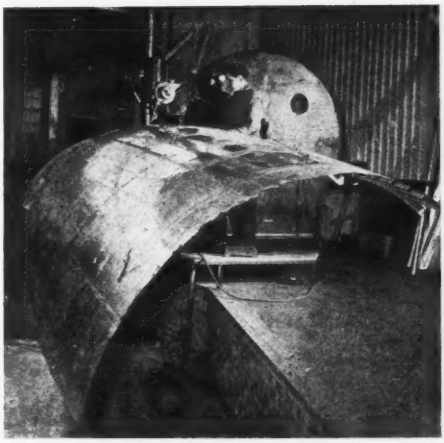


Fig. 53.

Another Erco riveting machine is used for double-curvature panels. A pit is dug in the shop floor so that the machine can accommodate large panels.

Figure 53 shows one of the double curvature panels being similarly riveted in another Erco machine. In order to accommodate this large panel it has been necessary to dig pits in the floor.

The fuselage track is believed to be rather an unusual and interesting system. Figs. 55, 56, 57 and 58 show the plan view of the floor on which tracks "A," "B," "C," "D" and "E" are mounted.

One of the Company's great aims has been to keep the external part of the fuselage free from jig structure so that the operators have ready access to their work, which adds considerably to efficiency and is conducive to good workmanship.

The whole of the fuselage floor building area is regarded as a surface table.

The accuracy of the floor itself or the rails which are mounted on the floor and form the track, are of no great concern; the accuracy and flatness of this large area actually depends upon the alignment of a number of Vee blocks and small flat surface stools (Fig. 54).

It is considered that the horizontal plane of this area is accurate to within plus or minus 1/32nd inch.

The jigs which are used on this floor to locate the various elements of the fuselage have been designed in such a manner that

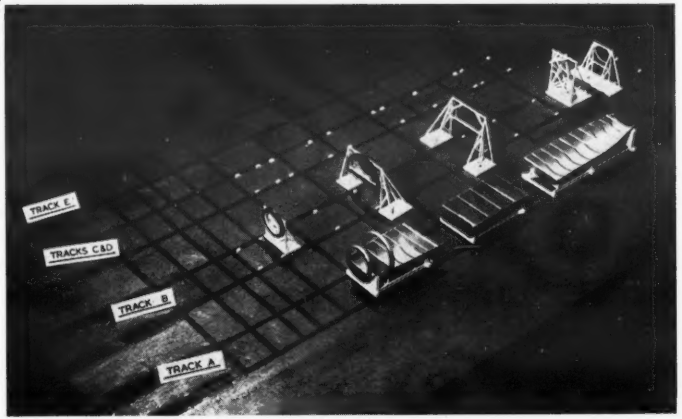


Fig. 55.

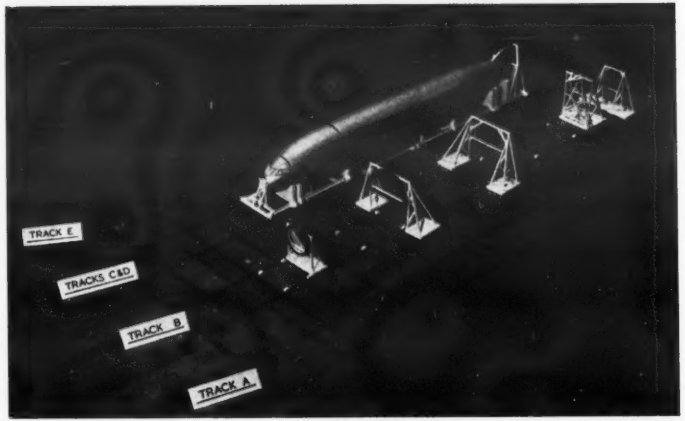


Fig. 57.

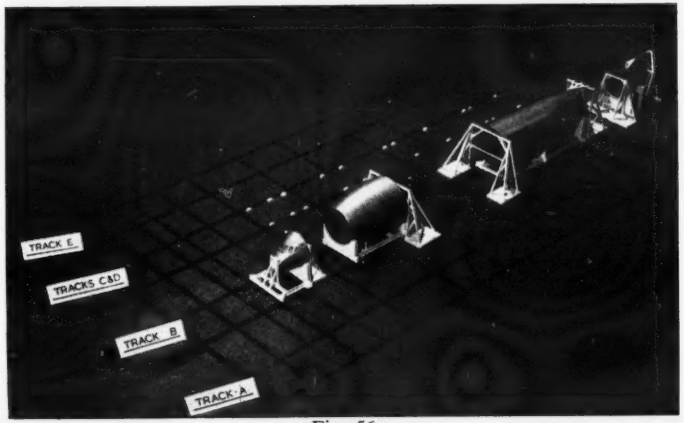


Fig. 56.

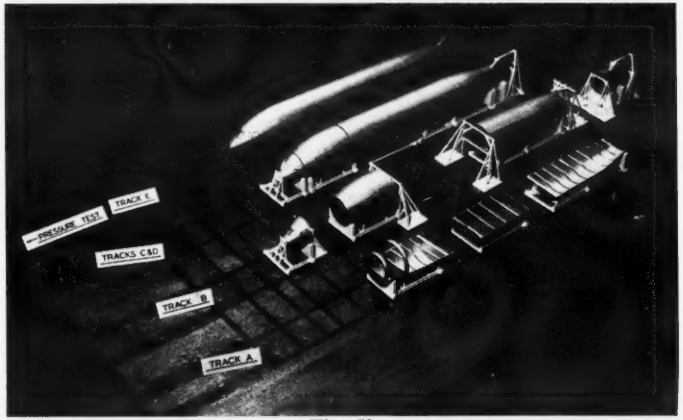


Fig. 58.

they can be used as mobile trolleys and can be transported, complete with components, between station and station on the track lines.

Once the jig trolleys have received the components such as keels, noses, and centre sections, from the initial static building jigs, they can be readily transported to any station on the track for the purpose of completing the operations which eventually build up the whole of the fuselage.

These jig trolleys are each fitted with Vee blocks and surface pads which correspond with, and can be mated to, any of the Vee blocks and surface plate stools on the line.

By this means a simple series of fuselage building jigs have been produced economically which, by adding four track wheels, become a substantial trolley which can handle the large and heavy components. This enables these components to be moved into any station position on the track with only the minimum of effort.

A simple screw jack arrangement attached to the wheel of each trolley, and operated by a standard spanner, enables the jig trolley to be raised or lowered off on to the track rails and placed in position on the Vee blocks. When in position on the Vee blocks the trolleys are definitely located in relation to a static portion of the jig which is built into the floor. This static portion of the jig, together with the trolley, forms a substantial and accurate jig for the completion of the operations on the component during the time it is being built into the elements which finally form the fuselage.

In order to transfer the jig trolleys from one track to another, a simple substitution for turntables has been arranged in the form of a nine inch square steel plate placed at intervals in the rails. This enables the trolley wheels to be turned through ninety degrees and wheeled from track to track on the rails which join one track to the other.

Fig. 54.

The surface plates and Vee blocks which ensure the accuracy of the mobile and fixed jigs on the fuselage assembly system. (*See also* Figs. 55, 56, 57 and 58.)

At each station there is only one fixed piece of jig structure which controls the location of skins, pressure domes, canopies, and so on, which are to be mated to the component contained on the jig trolley. This fixed structure and the jig trolley when located on the Vee blocks accurately control the location of the parts in relation to each other, so that they can be built on to the component which is located on the jig trolley.

On Fig. 55 track "A" shows rear and front keels which have been man-handled on to the jig trolleys. The operations consist of finishing any internal parts which have not been possible in the building jig. On Fig. 56 track "B" shows the front and rear keels and canopy in position. On this track, fuselage side skins, rear and front, pressure dome and canopy top are completed. On Fig. 57 track "C" shows components completed on track "B" transferred to this track for the purpose of completing the front fuselage attachment to the canopy, the attachment of pressure floor and centre section, front and rear fuselages, the completion of fuselage sides and the attachment of the rear cone.

Figs. 55, 56, 57, and 58 (*on the opposite page*) show a model illustrating the various stages in the fuselage assembly lines. All the fuselage sub-assemblies are mounted on mobile jigs which can be moved, on a system of rails, from one track to another. The lower front and rear keels are man-handled from their assembly jigs on to their trolleys on track A (Fig. 55). The only fixed jigs are on track B (Fig. 56) where the location of skins, pressure domes and canopies is controlled. The mobile jigs are brought into position and located accurately in place in relation to the fixed jigs by means of Vee blocks and surface plates (Fig. 54) set into the floor of the shop. The accurate location of each trolley is ensured by Vee blocks and surface plates. The trolleys are then moved on to tracks C and D (where again the accurate location of each trolley is ensured by Vee blocks and surface plates) for the final joining of the completed main fuselage components (Fig. 57). On the final track all the outstanding operations are completed and a preliminary leak test of 2 lb./sq. in. is made. The fuselage is then moved outside the hangar for its final pressure test of 11 lb./sq. in. (Fig. 60).

Similar operations are made on track "D."

The alignment of the centre section in relation to the centre line of the fuselage is extremely important, since this finally decides the squareness of the wing to the centre line of the aircraft. Fig. 59 shows the method used for checking the alignment of the fuselage, which consists of a tubular straight edge which is calibrated to be dead square with the centre line of the centre section, prior to it being attached to the fuselage.

With the centre section in position, and ready for attachment to the fuselage, plumb bobs are dropped from each side of the straight edge to indicate its relative alignment to the fuselage centre line by the position of the plumb bob heads in relation to index plates which are located in the floor.

Fig. 60.

A completed fuselage outside the fuselage construction shop about to undergo its "proof" pressurisation test before being moved to the assembly lines.

It is possible to adjust the centre section by shims under the centre fittings until a correct alignment has been obtained.

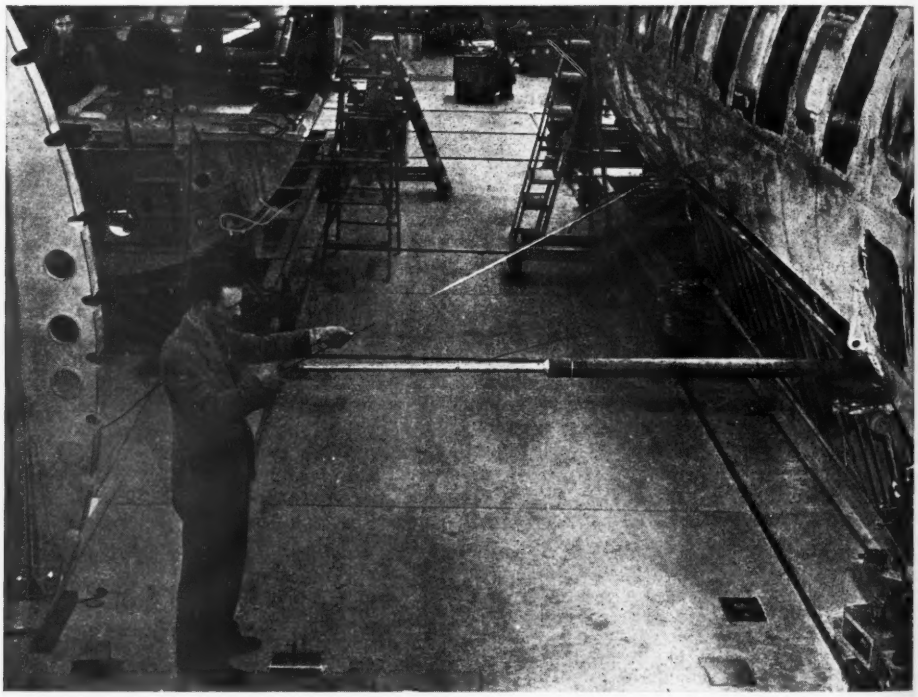


Fig. 59.

Checking the alignment of the fuselage to the centre section before attaching the latter to the fuselage body. The tubular straight edge is calibrated to be dead square with the centre line of the centre section before it is attached to the fuselage. With the centre section in the position, plump bobs are dropped from each side of the straight edge to indicate its relative alignment to the fuselage centre line by the position of the plumb bob heads in relation to index plates located on the floor.

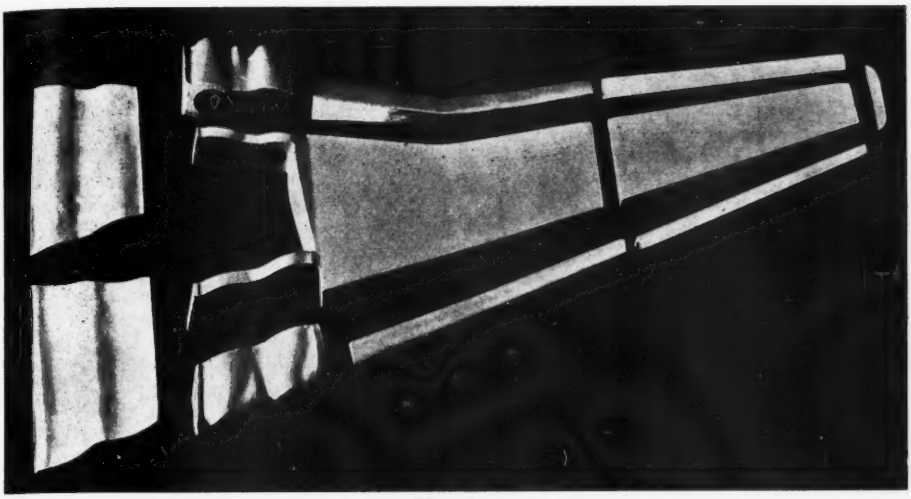


Fig. 61.

An exploded model of the Comet wing showing the breakdown of the main components into stub wing and extension wing, each with separate leading edges and flap and aileron sections. The air intakes, top and bottom, engine cowlings and jet pipe cowling assemblies are also shown.

Fig. 62.

A model of the final assembly line at Hatfield. There are two lines of Comet fuselages, both of which are served by a single line of wings. Each fuselage runs along its track on the same trolley that it retained after the boxing-up process in the fuselage shop.

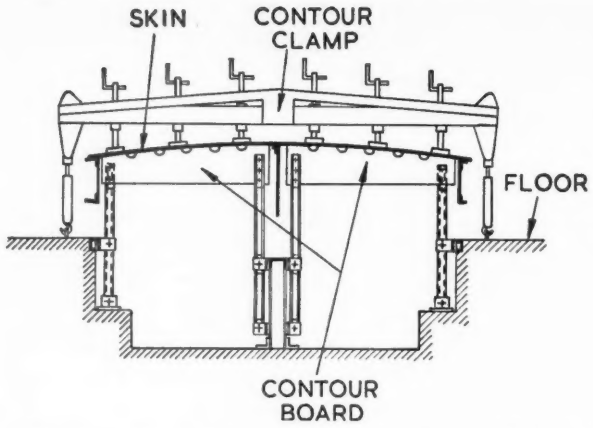


Fig. 63.
A diagram of the operation shown in Fig. 65 (*below*)—the carefully controlled attachment of the wing skins to the ribs.

Exceptionally good results have been achieved with this method and taking diagonals on the one-hundred-and-ten feet span of wing to the rear cone of the fuselage, the difference of only 0.4 inch has been measured between either diagonal.

When the centre section is finally attached, all other jig trolleys are removed, leaving the fuselage standing on the centre section trolley only.

The fuselage is then moved on to the final track, track "E," where all outstanding

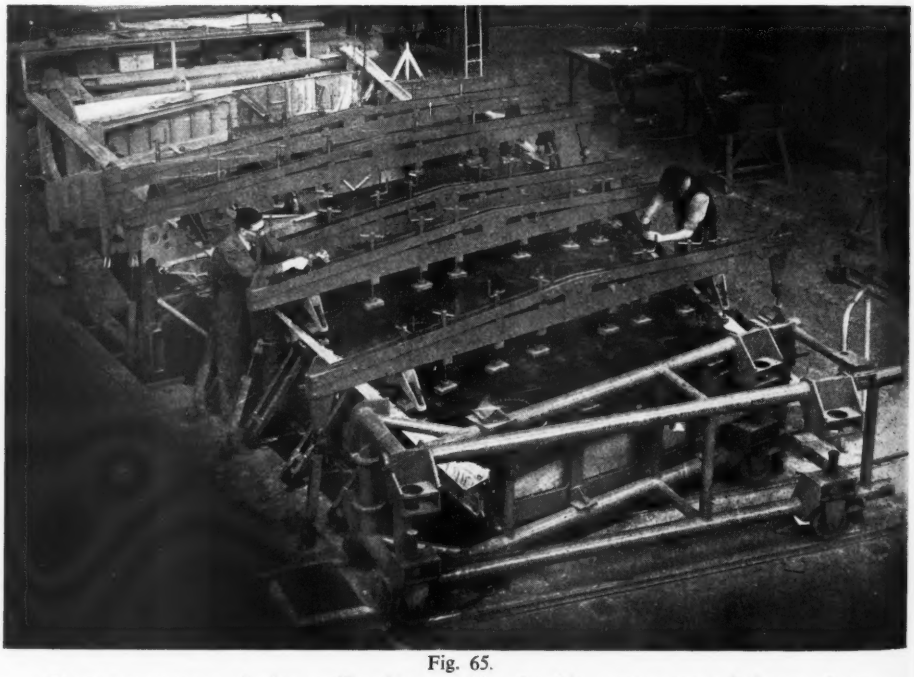


Fig. 65.
To ensure accuracy of wing profile when attaching the skin, contour control clamps, shown in position on the wing jig in this picture, are used. The method is illustrated diagrammatically in Fig. 63 (*above*).

Fig. 64.
The stub-wing building jigs are static and are built over pits to allow easy access from above and below. On completion of the bottom surface of the wing, the component is turned over to be transferred to a similar jig for completion of the upper surface plating.

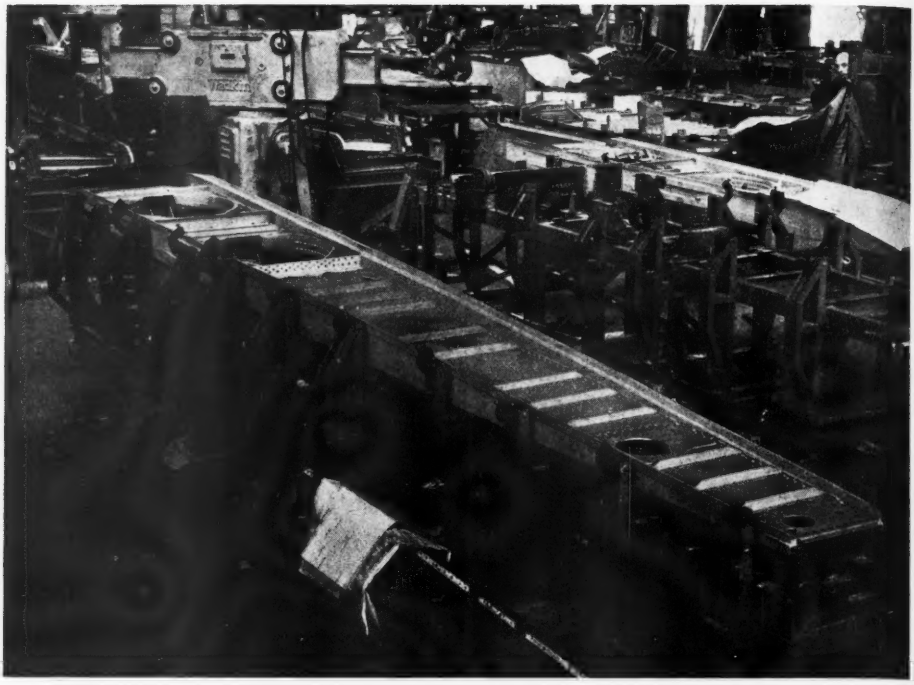


Fig. 66.
The main spar of the stub wing in the production jig. This jig, which is orthodox in design, was originally produced by the experimental department and later transferred to the production shop with only such minor modifications as were needed to speed up production time and ensure interchangeability.

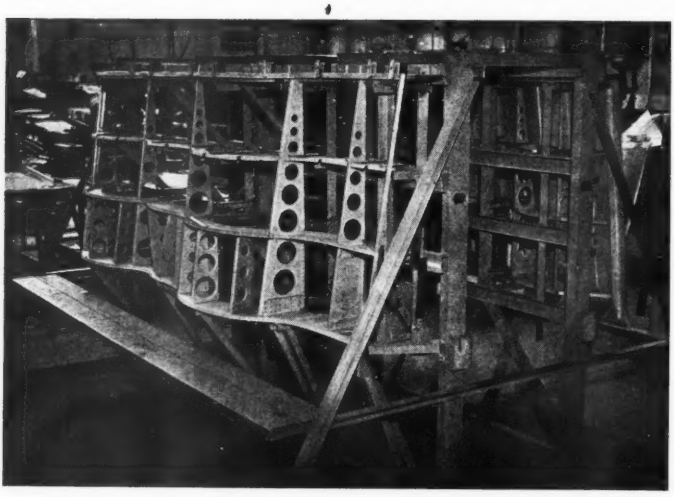


Fig. 68.
The jig for the assembly of the inboard section of the flaps.

operations are completed, and a preliminary leak test of 2 lb. square inch is made. Fig. 58 shows the tracks complete with components.

When this operation is completed and satisfactory, the fuselage is wheeled out of the shop, still on the track, to a position on the aerodrome where the 11 lb. square inch pressure test is applied.

It is not possible to do this test in the shop because, should a failure occur while approaching the 11 lb. square inch pressure, the bursting of the fuselage would be catastrophic. Fig. 60 shows the fuselage, which has been wheeled into the open where the pressure test will take place.

CONSTRUCTION AND TOOLING OF THE WING

The breakdown of the wing is shown in Fig. 61, and demonstrates clearly the elements which eventually complete the stub wing structure.

The wing building track is constructed on similar lines to the fuselage track.

The stub wing building jigs are static, but when the component is withdrawn from these jigs, subsequent operations are made on the track and all components are transported to the various stations on mobile jig trolleys.

The complete track circuit provides stations for the operation of drilling the stub wing attachments to the fuselage, for fuel tests, the attachment of engine cowling, engine cowling doors, air intakes, jet pipe cowlings, the attachment of the leading edge, and the installation of ailerons and flaps. This track is shown in Fig. 62.

The stub wing building jigs are rather unorthodox and have been designed with three principal features in view:—

(1) To give all operators easy access to their work so that they have every opportunity of producing a first class job.

(2) All operations in the jig to be of such a working height that personal fatigue will be eliminated.

(3) To obtain an accurate aerofoil when attaching wing skins.

Figure 63 shows a diagrammatic cross section of the jig, and Fig. 64 a general view of the jig. Fig. 65 shows the contour control clamps in position.

The spar building jig is an orthodox building jig, but emphasises again the liaison between the Production and Experimental Departments in that the original jig was produced by the Experimental Department and taken over by Production to be modified in such a way that it would ensure production times and interchangeability (Fig. 66).

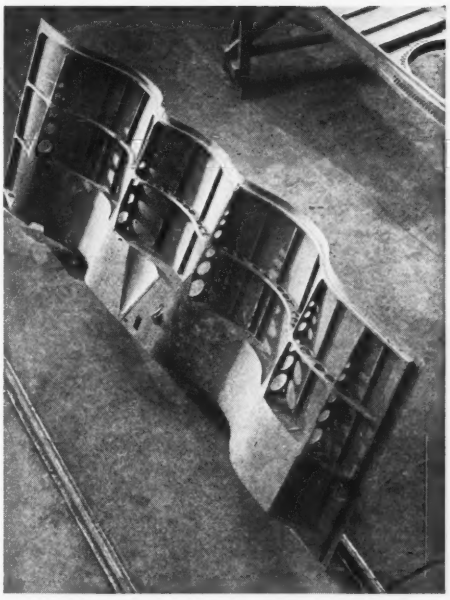


Fig. 67.
A finished section of the port inboard flap. It is of unusual shape because of its position underneath the engine tailpipes.

The same remarks apply to the rather unusual design of the flap (Fig. 67), the jigs of which are shown on Fig. 68. The stub wing building jigs are shown on Fig. 69.

The stub wing called for very special attention and as this portion of the wing is an integral fuel tank, great accuracy is necessary in the manufacture of mating components.

As an example, the method of producing the rather complicated shaped wheel well wall, which traverses across the wing in several directions, is probably worth mentioning. Fig. 70 shows a diagrammatic cross section of this unit, and Fig. 71 the actual unit ready to assemble in the wing jig.

The profile of the landing angle, owing to its path across the wing, requires the production of a winding bevel and at the same time the depth of this member between

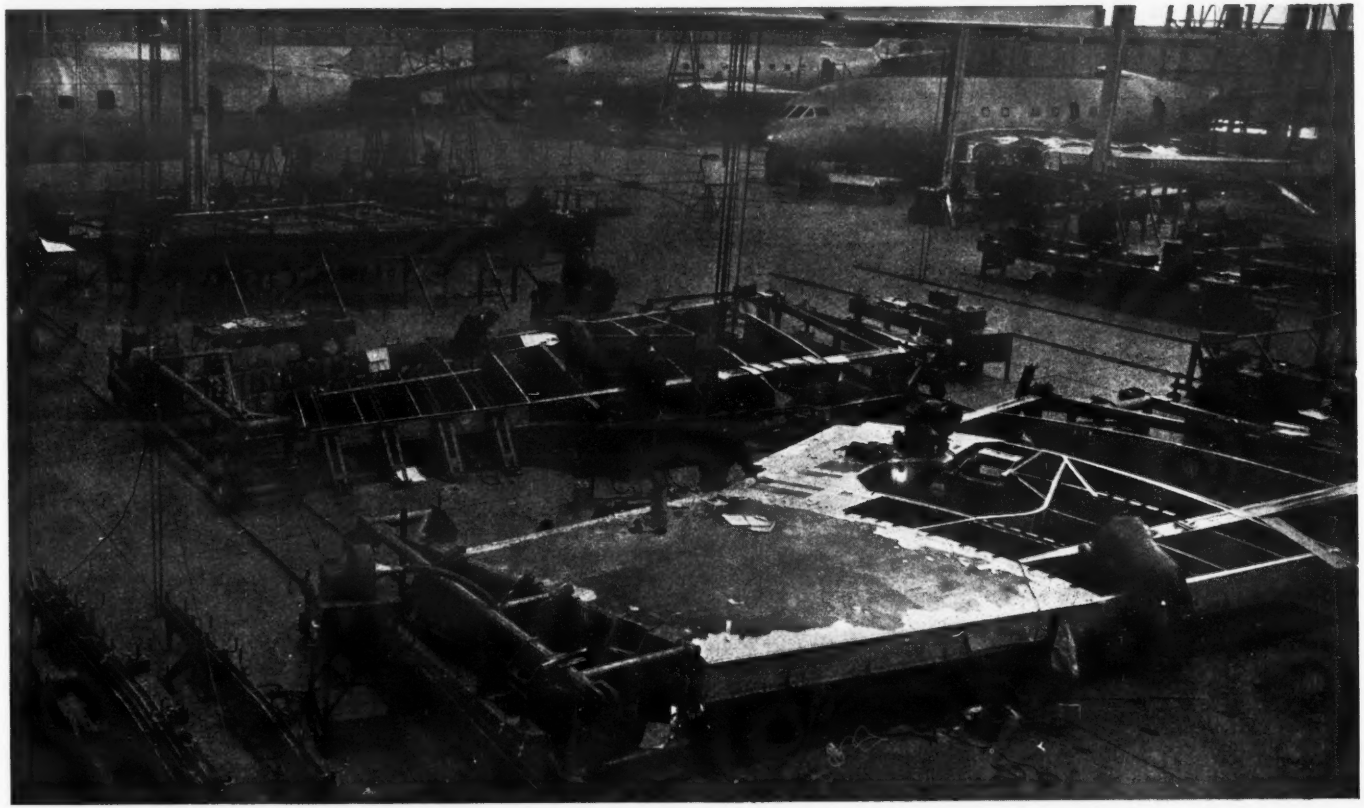


Fig. 69.
A general view of the Comet assembly lines at Hatfield. In the foreground are the starboard wing jigs.

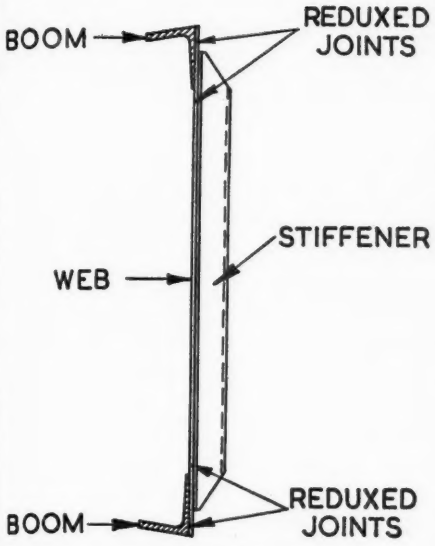


Fig. 70.

A diagram of the cross section of the wheel-well wall. (*See also* Fig. 71 and Figs. 72-75 on page 494.)

top and bottom skins must be accurately controlled and a perfect wing contour must be produced.

The landing angles also have to be kept within tight limits for weight control purposes. Fig. 72 shows the tooling set up for this job. It consists of two rails which are accurately fixed in relation to each other, giving the correct contour and bevel of the landing angle. To obtain the correct depth, contour and bevel, these rails were set by an accurate wooden model. The depth at all points is controlled by limit stops set in relation to the profile edge of the rails.

The first operation on this component is to Redux the angles to the web. These angles are controlled during this operation as accurately as possible, but the final accuracy is produced when the assembly is placed in the jig and machined by a rotary hand miller which is traversed across the surface of the angles, removing approximately 1/32nd inch of metal. The rails control the depth of cut, also the correct contour and winding bevel.

After machining one face the component is reversed and the machined face of Operation One is located against a limit stop which determines the correct depth of the component, while the second operation of machining the opposite angle is being done.

This is a quick and accurate method and the units have been kept within the tolerance of approximately 0.01 inch. The final thickness of the angle is made by a router fitted with control rollers which locate on the surface of the angle which has previously been machined and by traversing the component through this router, the correct thickness and inner bevel is produced (Figs. 73, 74 and 75).

The operation in the first jig is the location of spars, ribs, wheel well walls and bottom skins.

On completion of this operation the wing is transferred from No. 1 jig to No. 2 jig, and is turned over through one-hundred-and-eighty degrees. The top skin is attached in a similar manner in No. 2 jig.

To enable this to be done the bottom skin which was previously fitted must be removed to give access for the operators to complete their work inside the wing, which includes fastening off the top skin to the ribs and spars.

The stub wing is then removed from the jig, placed in position on the drilling jig, and while the spars are being drilled and reamed for attachment to the fuselage centre section, the bottom skin is also being attached.

By eliminating the operation of attaching the bottom skin while in No. 2 jig, and doing this concurrently with the drilling operation, the time cycle has been equalised in Nos. 1 and 2 jigs.

Figure 76 shows the drilling operation of the stub wing, which consists of drilling and reaming 252 tight limit holes for attachment of the wing to the centre section. The method adopted is of interest and has ensured complete interchangeability between fuselage, centre section and stub wings.

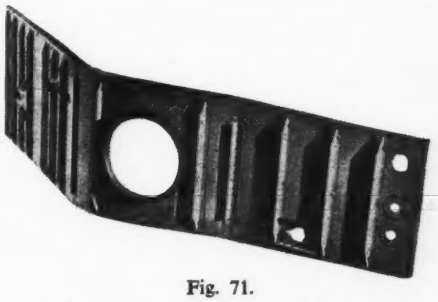


Fig. 71.

The wheel-well wall, which requires accurate jigging and machining.

A general view of the Comet assembly lines at Hatfield. In the foreground are the starboard wing jigs.

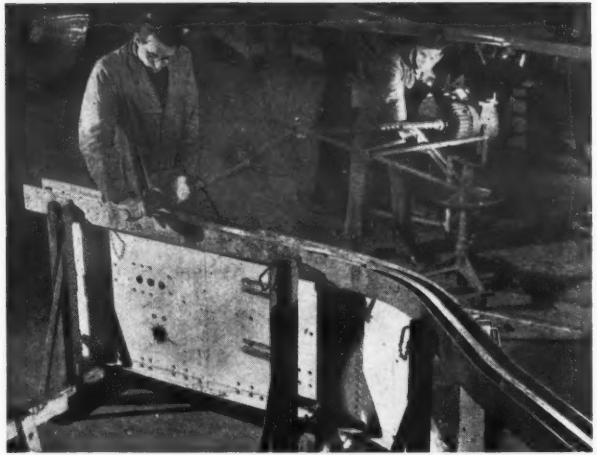


Fig. 72.
The method of producing the wing profile and winding bevel on the landing angle of the wheel-well wall. The depth of the member is also controlled in this jig set-up. A rotary hand miller is used for machining this component.

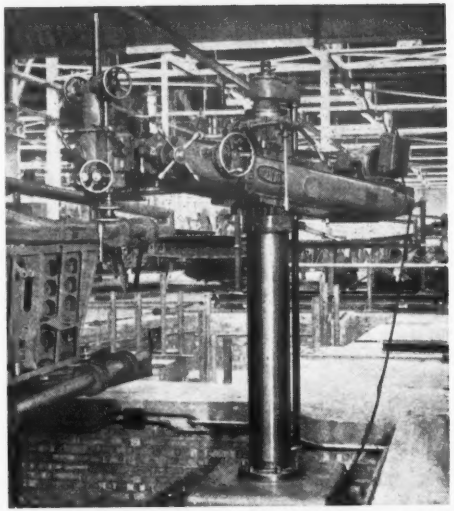
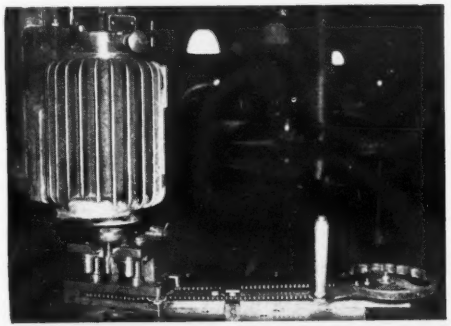
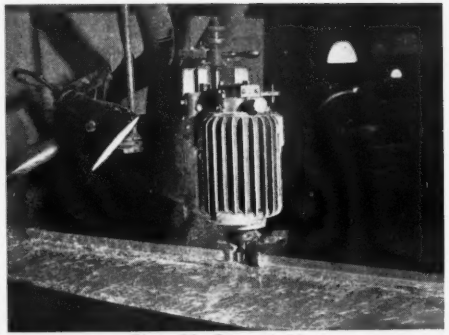


Fig. 77 (*right*).
A close-up of one of the Asquith radial drills used on the centre section drilling jig (*see also* Figs. 76, 80 and 81). Other jigs are arranged nearby to make the fullest use of these machines (Figs. 78 and 79).





Figs. 73, 74 and 75.
A close-up of a router system used to machine the winding bevel on landing angles. This method accurately controls the thickness and is a necessary control for weight limits.

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A close-up of a router system used to machine the winding bevel on landing angles. This method accurately controls the thickness and is a necessary control for weight limits.

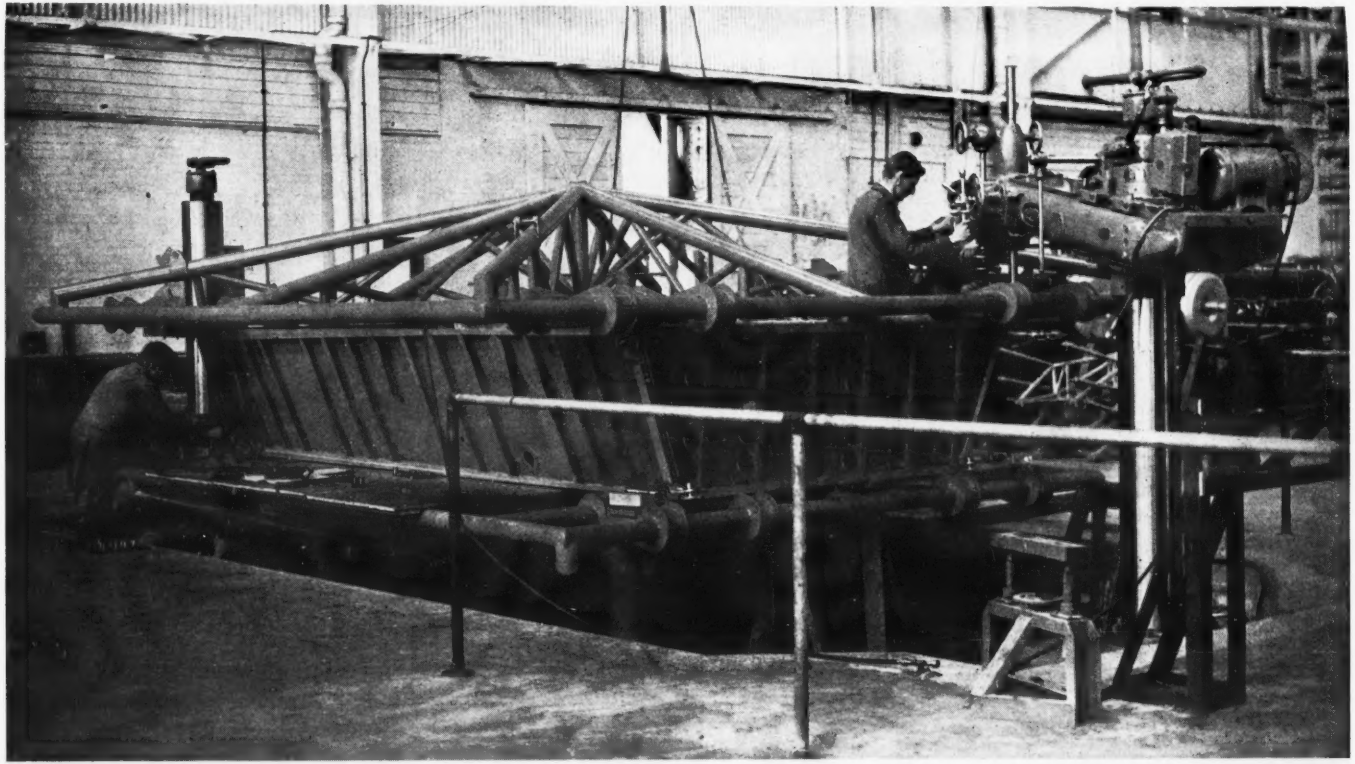


Fig. 76.
A view of the jig used for the accurate drilling of the 252 tight-limit holes of the fuselage centre section and the stub wings. In this picture a centre section can be seen in position on the jig, and an operator is using one of the two special radial drills on the wing-root fittings. *See also* Fig. 18 (page 466).

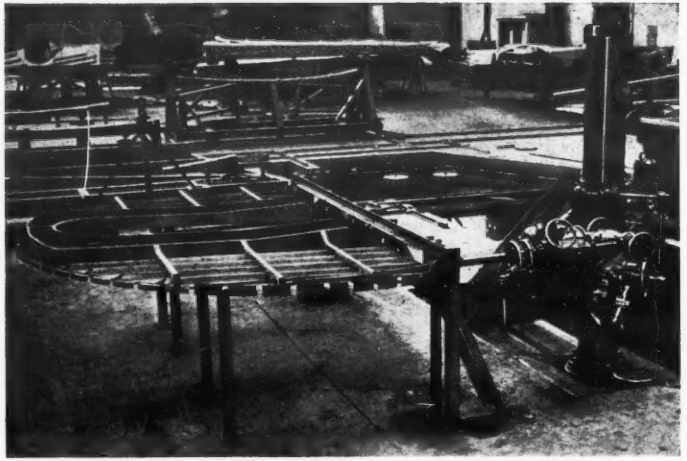


Fig. 78.
Horizontal drilling and reaming of the main fuselage bulk-head.

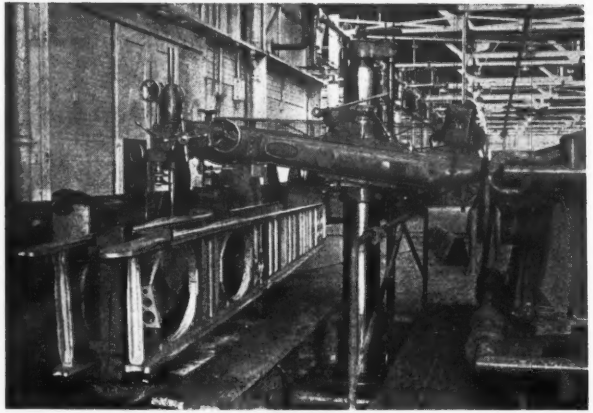


Fig. 79.
Other uses to which the special radial centre section drill is put are shown in this photograph and in Fig. 78 (*opposite*). Fig. 79 shows the spar, which is located near to the centre section, being drilled and reamed.

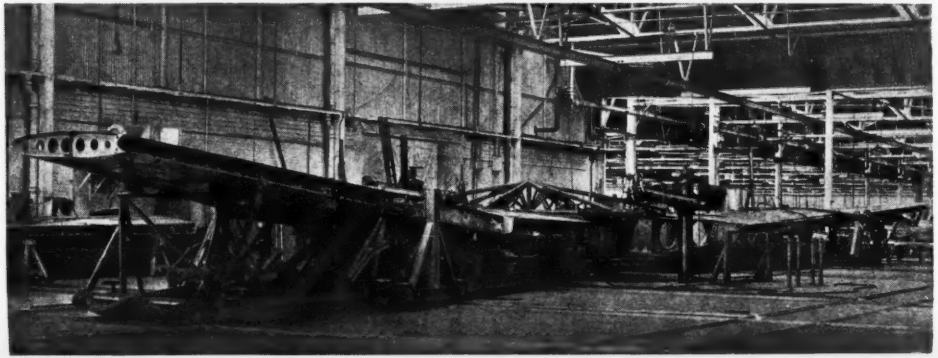


Fig. 81 (*left*).
Another view of the centre section drilling jig showing the stub wings in position for their root fixings to be drilled.

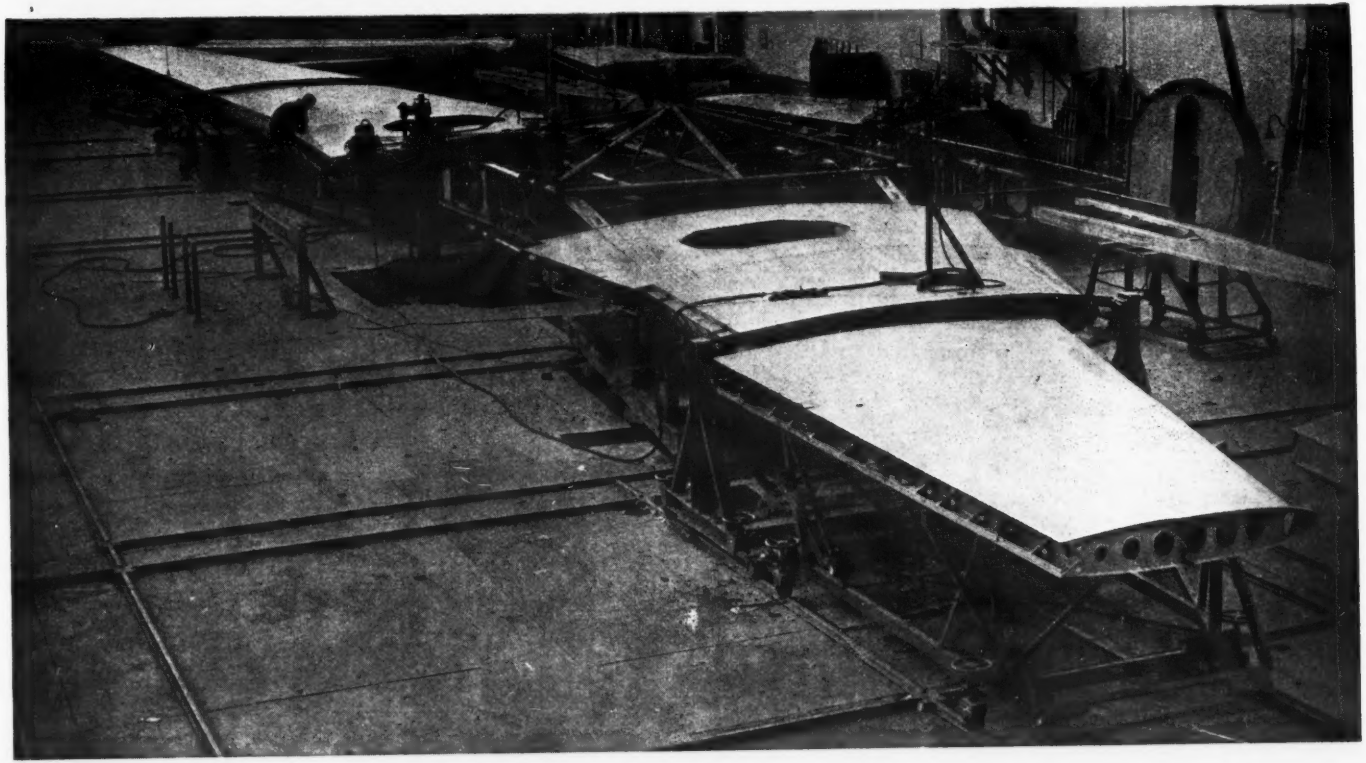


Fig. 80.
The stub wing and extension lined up in the centre section drilling jig. This jig is designed to ensure complete interchangeability and the absolute accuracy of the wing unit as regards the dihedral, incidence, and sweepback.

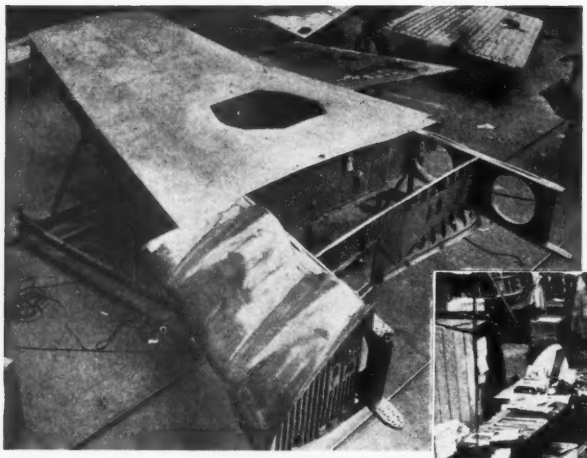


Fig. 83 (*left*)
A view of a starboard stub wing showing the final operation on the line—the attachment of the air intake.

Figs. 85, 86 and 87 (*right*).
Two views of the air intake assembly jigs are shown in Figs. 85 and 86. Fig. 87 shows the attachment of the engine cowling to the stub wing.

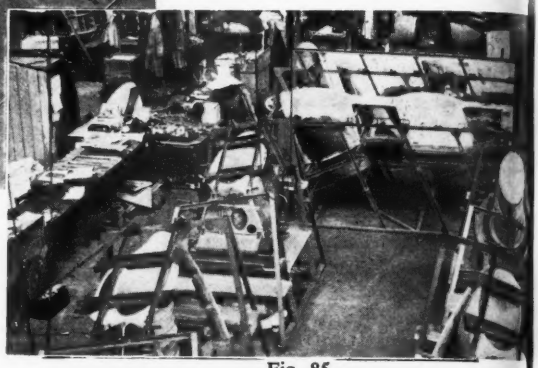


Fig. 85.

Fig. 82 (*above*).
The special clothing and equipment used by the operator working in the confined space of the wing during the application of the Bostik protection fluid. By means of this clothing and equipment he is provided with a supply of fresh air and communication with an assistant outside.

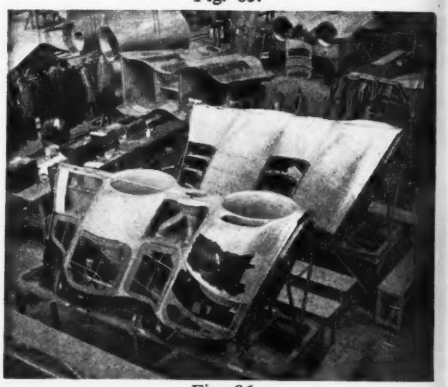


Fig. 86.

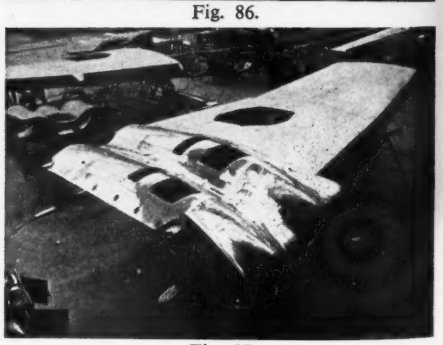


Fig. 87.

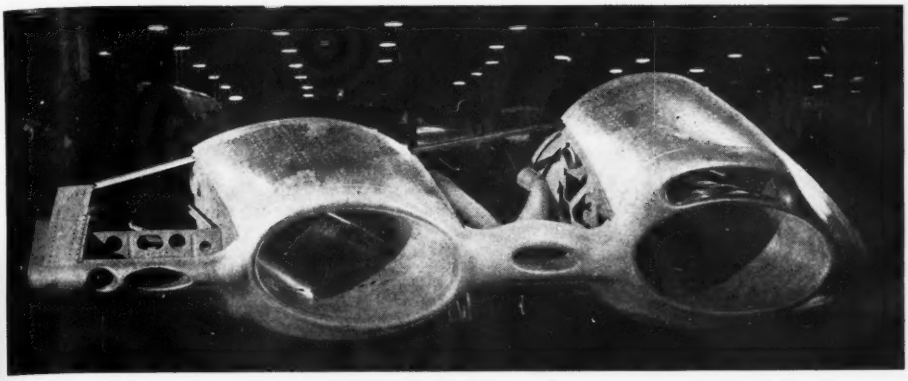


Fig. 84.
The starboard side engine air-intake in the course of assembly. This process is one of the more complicated sub-assemblies, but a reasonable production time-cycle was achieved by the construction of the jigs shown in Figs. 85 and 86.

Fig. 88.
The plaster mould from which concrete press tools for the engine cowling were cast; the matrix was filled with building bricks and then moulding sand to within about an inch of the tops of the lofted steel plates. The mould was then finished to within fine limits with plaster of Paris and a final coating of shellac (*see also* Figs. 89, 90 and 91). The final stage in the construction of the mould is shown in Fig. 20 (page 468).

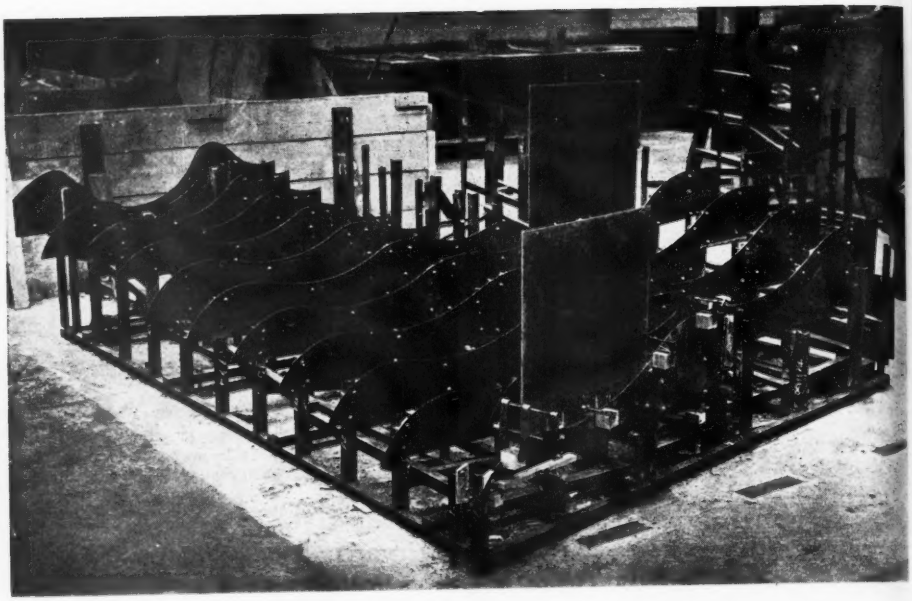


Fig. 89

Fig. 90.

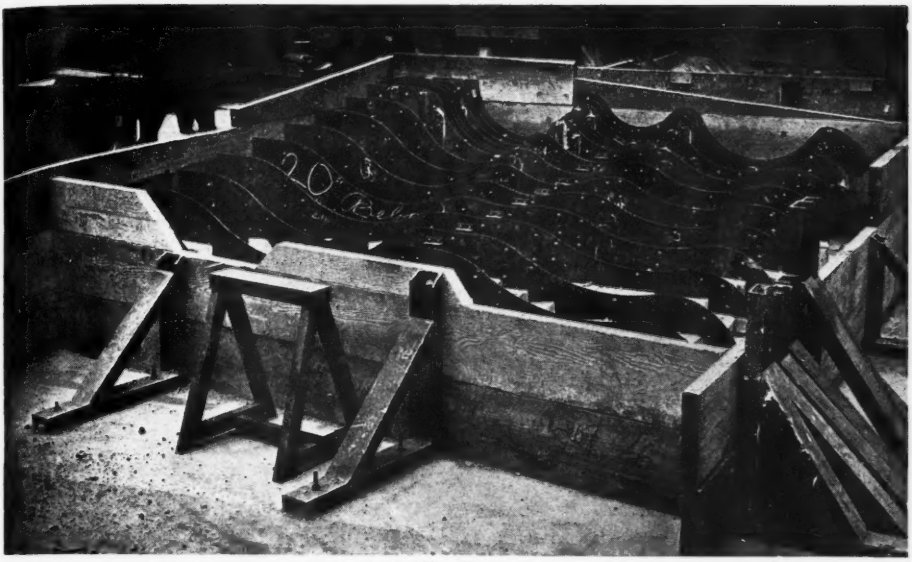


Fig. 91.

Figs. 89 and 90 (*opposite*) and 91 (*above*).

These figures show further stages in the construction of the plaster moulds, from which concrete skin and stiffener stretcher press tools were made. The lofted plates are seen in position in Figs. 89 and 90 and in Fig. 91 the brick filling foundation of the mould is in place. The next stage was to fill the mould to within about an inch of the top of the lofted contour plates with sand, the final finishing layer being of plaster. When all the necessary tools had been cast from these moulds the filling was removed and the matrix is used to form the final assembly jigs.

The method consists of a large drilling jig controlling the drilling of the nests of holes in top and bottom boom attachments of the front and rear spars to the fuselage centre section. These nests are also located in strict relation to each other about the centre line of the fuselage, longitudinally and thwartwise. Two special radial drilling machines are employed to perform this drilling and reaming operation (Fig. 77).

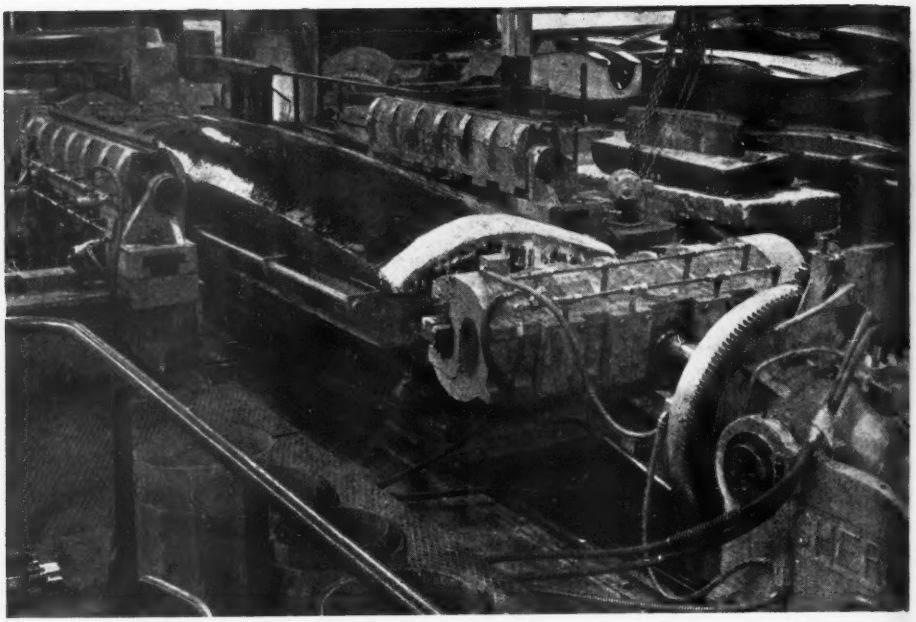
The drill heads of these machines are arranged to revolve through a complete revolution of 360 degrees, and to drill at any compound angle with the 360 degrees. With this machine jig drilling can be done vertically downwards through the top spar booms and centre section fish plates, and by dropping the drill heads and rotating them through 180 degrees the jig drilling operation can be repeated vertically upwards through the bottom spar booms. The gap traversed between the top and bottom booms is three feet, and gives an indication of the usefulness of these large radial drills.

Very economic use has been made of these radial drills by arranging other jigs in the locality of the main drilling jig.

One of the operations is the horizontal drilling and reaming of the main fuselage bulkhead (Fig. 78).

Another operation is a separate set up for the drilling and reaming of the close tolerance bolt holes used for securing the engine stiffening rings in the spar (Fig. 79).

Before beginning the drilling operation, the fuselage centre section is set up correctly in the drilling jig, the stub wings are wheeled into position, and the spar booms accurately located between the high tensile steel fish plates which form the attachment of wing spar to the centre section. The sweep back of the wing, the incidence, and dihedral angles are accurately set and checked by inspection prior to drilling (Figs. 80 and 81).



Figs. 92 (*above*) and 93 (*opposite*).
The large concrete tool used for stretching the longitudinal portion of an engine cowling (Fig. 92) was cast direct off a plaster mould. Fig. 93 shows the engine cowling being stretched on the Sheridan stretcher press.

When the setting is satisfactory, the drilling and reaming for the tight limit bolt holes through the fish plates and spar boom are completed in this jig. When this drilling is completed, the stub wings are withdrawn from the jig and before proceeding with any subsequent assembly they are taken on the track to a position outside the shop where a fluid test is given. Each stub wing is filled with two thousand gallons of paraffin and any weeps which may occur are remedied.

Although the actual sealing of the tank is made by an internal rubber seal, it is also given a thin coating of Bostik solution as an internal protection.

Because of the confined working space in the wing and the fact that fumes are given off by the Bostik solution, special precautions have had to be taken to prevent the toxic effect of these fumes on operators. Fig. 82 shows the clothing provided for the operators, which enables them to be given a fresh air supply during the time they are inside the wing. This suit is also provided with intercommunication telephones, and the operator is kept in constant touch with external personnel.

Following the fluid test, the wing is wheeled into several station positions on the track where the various elements are assembled. Fig. 83 shows the first operation, which is the attachment of the air intake to the wing and Fig. 84 shows the air intake subassembly. Figs. 85 and 86 illustrate the battery of jigs used in the production of the rather complicated air intake unit, all of which are necessary to give a reasonable time cycle.

The second operation is the attachment of engine cowlings, shown in Fig. 87.

One of the problems was to produce quickly and cheaply the tooling required for the engine cowlings, which are of a rather complicated shape, and for the access doors under the engine compartments. A plaster model was used for the manufacture of the tools and the accuracy of this was obtained by using lofted printer plates. The printer plates were made into a three-dimensional structure which was filled with plaster to give the accurate three-dimensional model. The complete plaster model is shown in Fig. 20.

One interesting point is the economic use

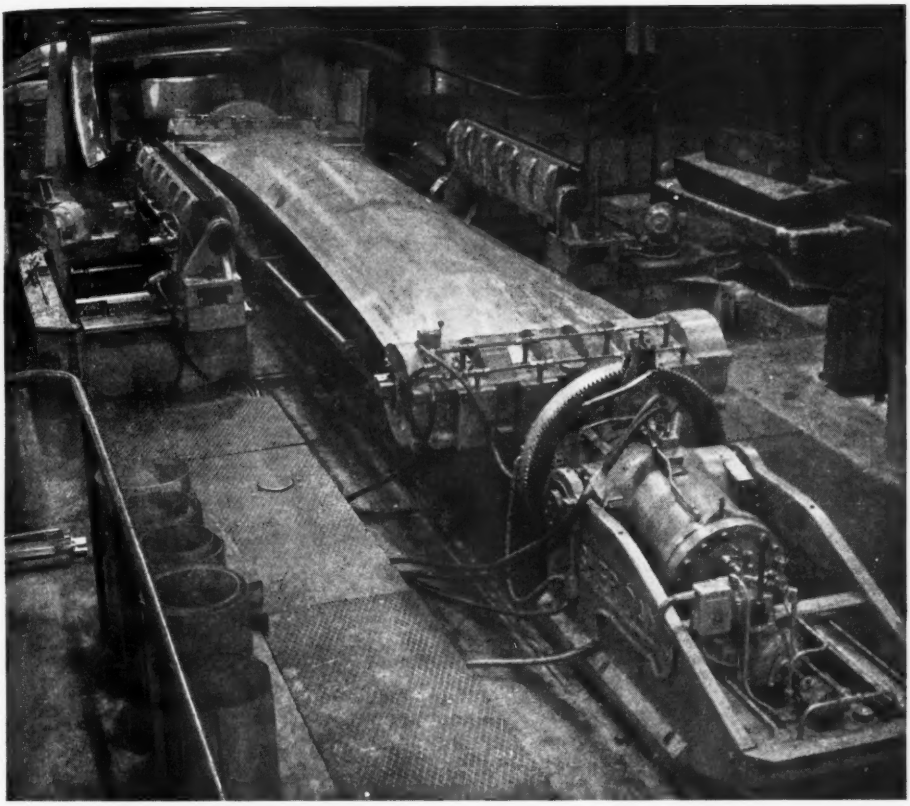


Fig. 93.

which was made of this particular model tooling.

The filling of the three-dimensional model was dealt with economically by partly filling the steel matrix with ordinary building bricks, on top of which a layer of moulding sand was rammed into position and formed to follow the contour of the loft plates, leaving approximately one inch from the top of the loft or former plates and the sand for filling with plaster (Fig. 88). Figs. 89, 90 and 91 show the actual model in the course of construction.

On completion of this three-dimensional model, all concrete stretcher press tools were cast direct on to the smooth and accurate surface of the model. Fig. 92 shows one of the large concrete stretcher press tools for the main longitudinal portion of the cowling, which was cast direct on to the model. Fig. 93 shows this tool in operation on the Sheridan stretcher press.

The time for pulling this complete cowl skin, which is twenty feet long and four feet wide, is ten minutes. The weight of the tool is approximately three tons.

The concrete mixture used is four to one, *i.e.* two cubic feet 3/16th in. sand, two cubic feet 3/8th in. shingle, and 90 lb. cement.

The surface of the tool is finished by smoothing with a portable abrasive disc, filling in the small porosity caused by air bubbles, after which it is given a priming coat and a final finishing coat of Phenoglaze. This produces a tough and smooth surface and it has been found by experience that this type of tool with this finish is excellent for stretcher press work.

The time for production of a tool of this size and weight is approximately seven days.

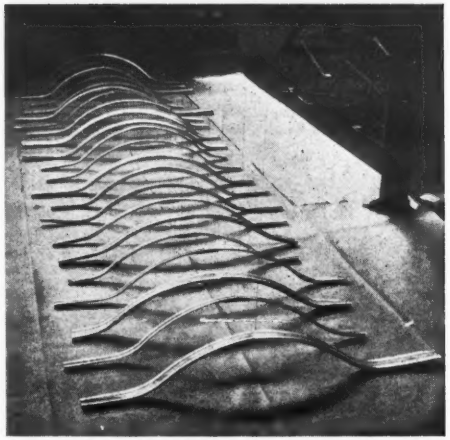


Fig. 94.

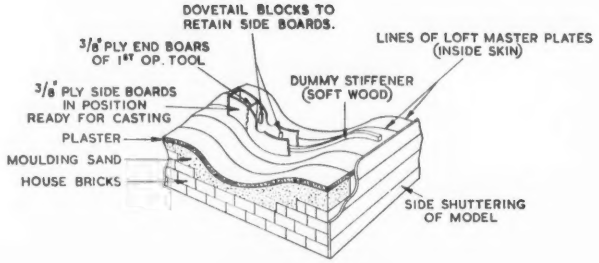

DOVETAIL BLOCKS TO RETAIN SIDE BOARDS.
3/8" PLY END BOARS OF 1ST OP. TOOL
LINES OF LOFT MASTER PLATES (INSIDE SKIN)
DUMMY STIFFENER (SOFT WOOD)
3/8" PLY SIDE BOARDS IN POSITION READY FOR CASTING
PLASTER
MOULDING SAND
HOUSE BRICKS
SIDE SHUTTERING OF MODEL

Fig. 95.

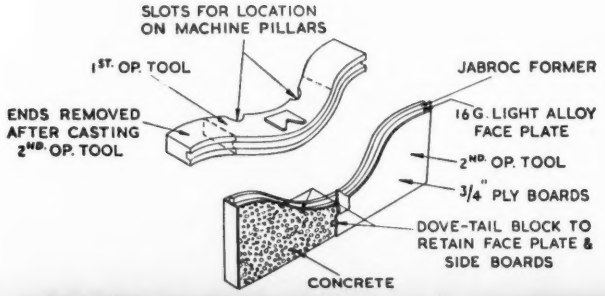

SLOTS FOR LOCATION ON MACHINE PILLARS
1ST. OP. TOOL
JABROC FORMER
ENDS REMOVED AFTER CASTING 2ND. OP. TOOL
16 G. LIGHT ALLOY FACE PLATE
2ND. OP. TOOL
3/4" PLY BOARDS
DOVE-TAIL BLOCK TO RETAIN FACE PLATE & SIDE BOARDS
CONCRETE

Fig. 96.

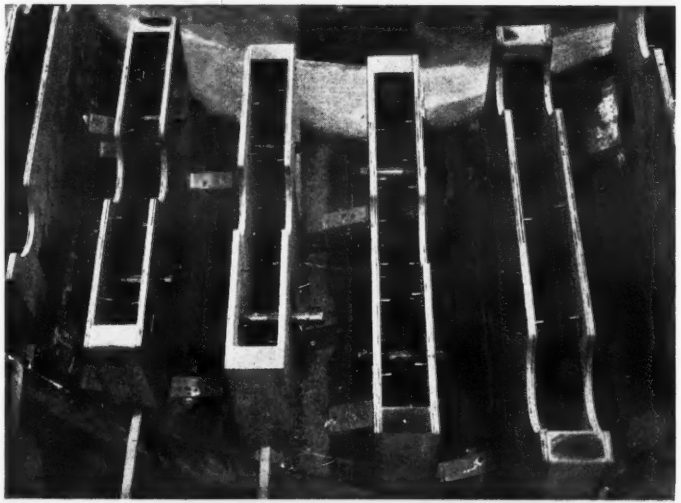


Fig. 97.

Fig. 98.

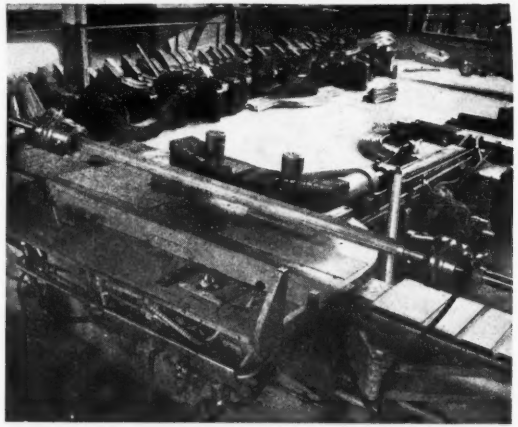


Fig. 99.

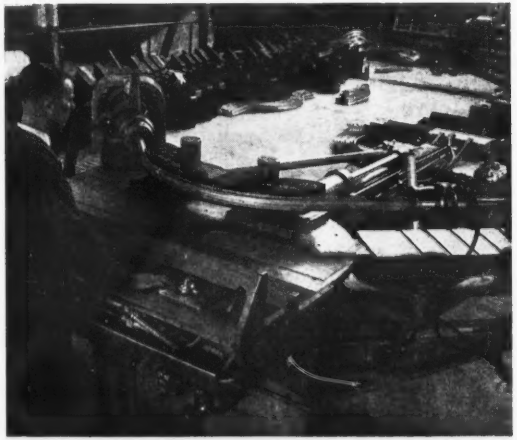


Fig. 100.

Figs. 94-100.

The figures on these two pages show some of the processes used for the engine. Figs. 95 and 96 show the way in which the tools used for forming the engine nacelle frames are made from the plaster mould. Fig. 94 shows some of the stiffeners of the engine cowl. Fig. 97 shows the three-ply boxes in which the tools are cast. Figs. 99 and 100 show the forming of a frame in the Hufford stretcher press. Fig. 98 shows a series of stretcher press tools used for forming the engine nacelle frames.

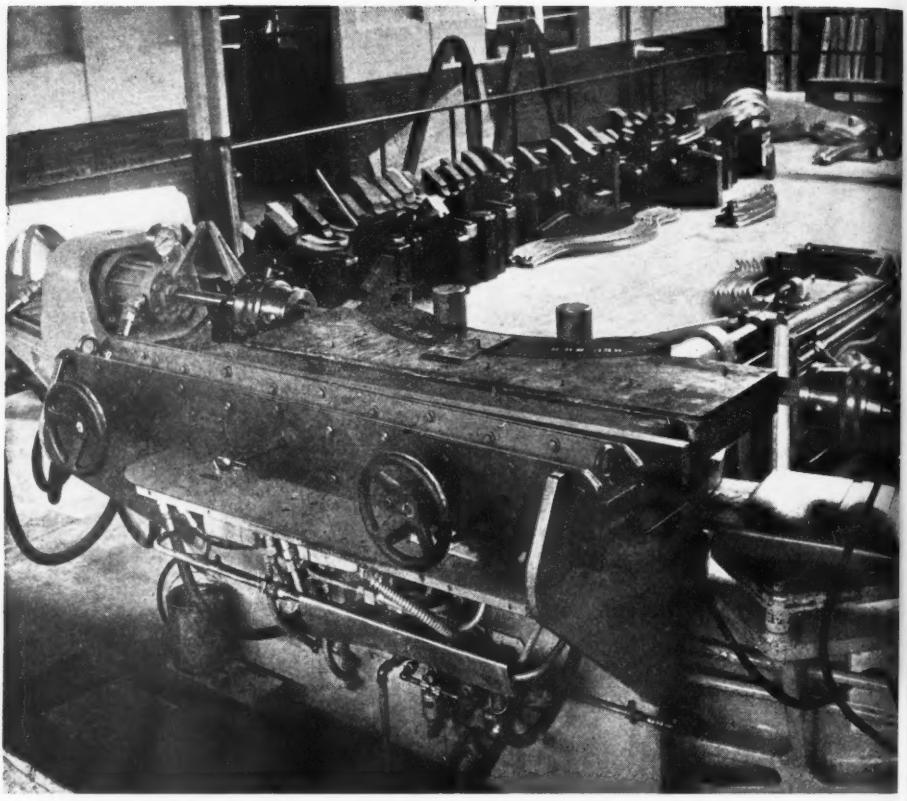


Fig. 101.

An interesting problem was the accurate and economic production of the large quantity of Hufford stretcher press tools required for the manufacture of the cross members in the engine cowling. It was decided to try, for the first time, the development of concrete tools for this job, which proved most successful.

The method of manufacturing these concrete stretcher press tools was to cast direct on to the same master model which was used for making the longitudinal skin. All the cross member tools were cast transversely on this model at whatever position they were located. This ensured the accuracy of fit; in fact, every cross member which has been made from these tools, to use the proverbial saying, has "fitted like a glove."

The method used was unquestionably a great success, taking into account the fact that most of these members have a reversed curvature in their transverse plane and a double curvature in their longitudinal plane.

By this means twenty-five pairs of tools per week can be built, using eight men. The total number of tools required for the top and bottom cowls, left and right hands, was 195.

Figure 94 shows the series of stiffeners used in the cowl and Figs. 95 and 96 show in diagram form the manufacturing system. The actual tool being cast is shown in Fig. 97 and the whole series of tools required for this work is shown in Fig. 98. Figs. 99, 100, 101 and 102 show the tools in use on the Hufford press.

In the production of the master plaster models the author considers that great economies have been shown.

The matrixes used for constructing the three-dimensional plaster models would have proved expensive if used for this purpose

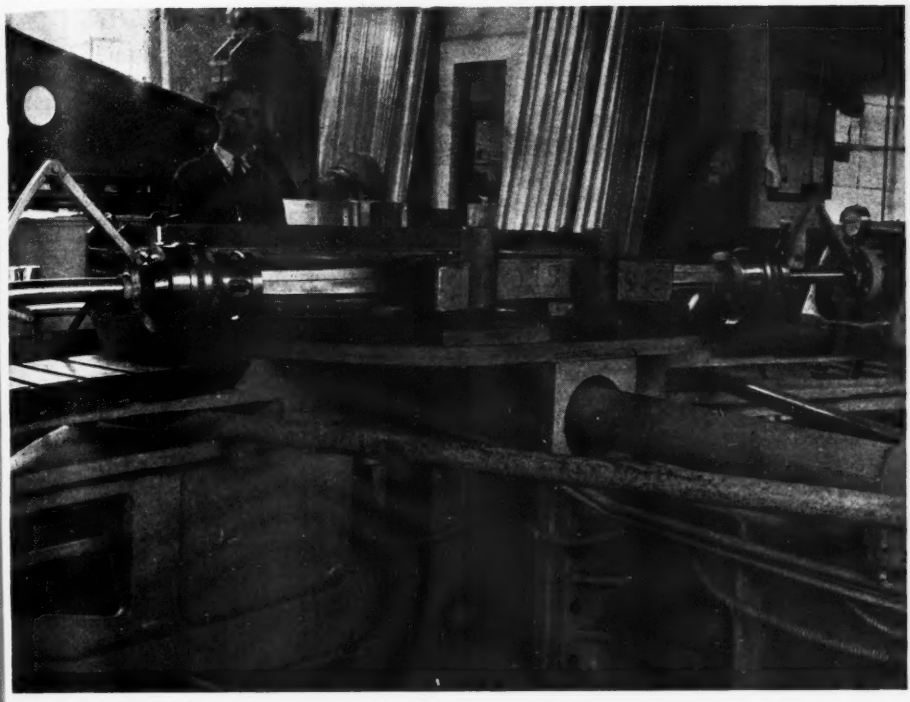


Fig. 102.
Figs. 101 (*opposite*) and 102 (*above*) .
Further views of the Hufford stretching machine showing the method of forming the reverse curvature of the engine nacelle frames.

only; but the production engineers decided that the steel matrixes used in the construction of the plaster model could be made to serve a dual purpose. By carefully arranging the matrixes which form the model and making them in eight separate handed units, representing the engine cowl doors, they could ultimately be used for assembly jigs for the construction of these doors (Figs. 103 and 104).

After all concrete stretcher press and Hufford tools had been made from the master model, the model was dismantled and the eight units were used for the manufacture of assembly jigs for the cowling doors. This was simply done by adding wooden facing strips to the 1/8th in. thick metal loft plates and providing hinge locations and trim lines (Figs. 105 and 106).

The great advantage of this method is the accuracy provided by using the actual loft plates for the dual purpose of making the model from which all tools are cast and afterwards transforming the matrix of the model into the actual assembly jig.

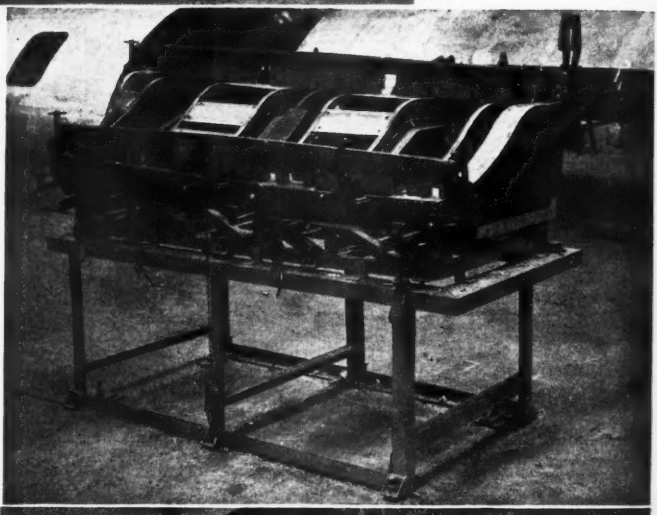
The fact that the stretcher press tools were all taken from the same mould formed by these plates, meant that the skins and cross members made by these tools all fit accurately into the assembly jig without any adjustment whatsoever.

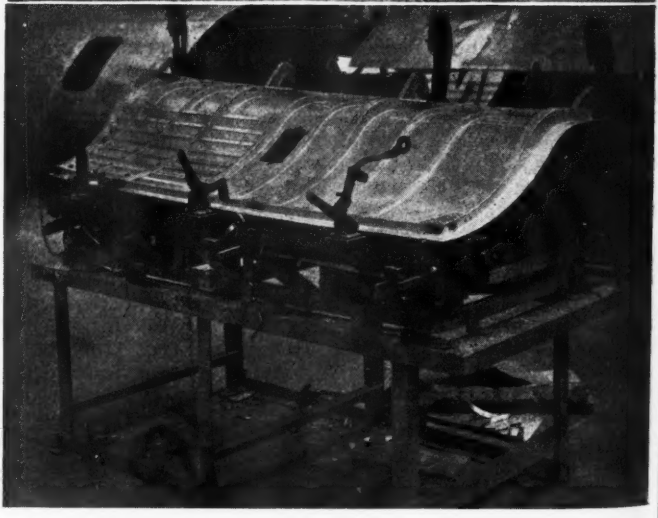
The third operation is the attachment of the leading edge to the wing, and Fig. 107 shows the fourth operation, the attachment of the rear cowling over the jet pipe. Fig. 108 shows the fifth operation, attaching the flaps to the wing.

The production of the leading edge presented one of the difficult problems, particularly as the contour had to be produced to a tolerance of 0.01 in. (Fig. 109).

The production of any leading edge in 12 SWG DTD.710 with a minimum curvature of one-and-a-half inches on the tip within these

Fig. 103 (*above*).
A set of cowling doors, direct from the jigs, ready for assembly on the aircraft.





Figs. 105 and 106 (*right*).
An assembly jig for a cowling door which was built up from the matrix used in the construction of the plaster model. This was simply and economically done by adding wooden facing-strips to the $\frac{1}{8}$th in. thick plates and providing hinge locations and trim lines.

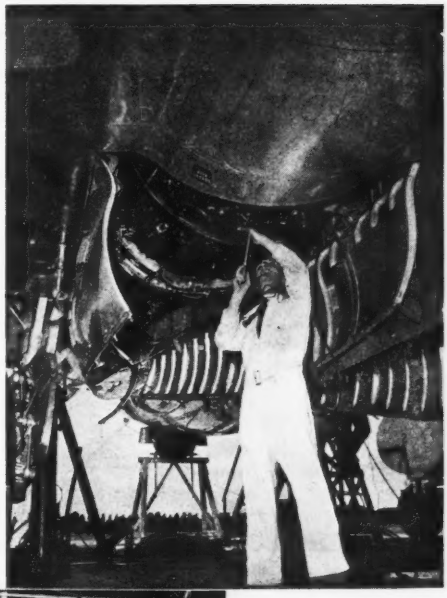


Fig. 104 (*right*).
The engine cowling doors in position on the aircraft. They give good accessibility to the whole of the underside of each engine.

Fig. 107 (*left*).
The rear jet pipe fairing being fitted to a wing stub.

Fig. 108 (*left*)
Final assembly stages. A port stub wing with flaps, air brakes, leading edge, engine cowling, etc., in place and ready for attachment to a fuselage.

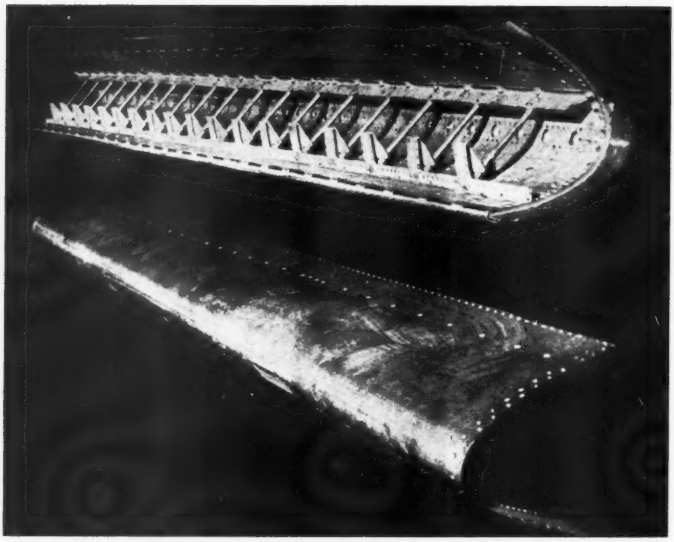
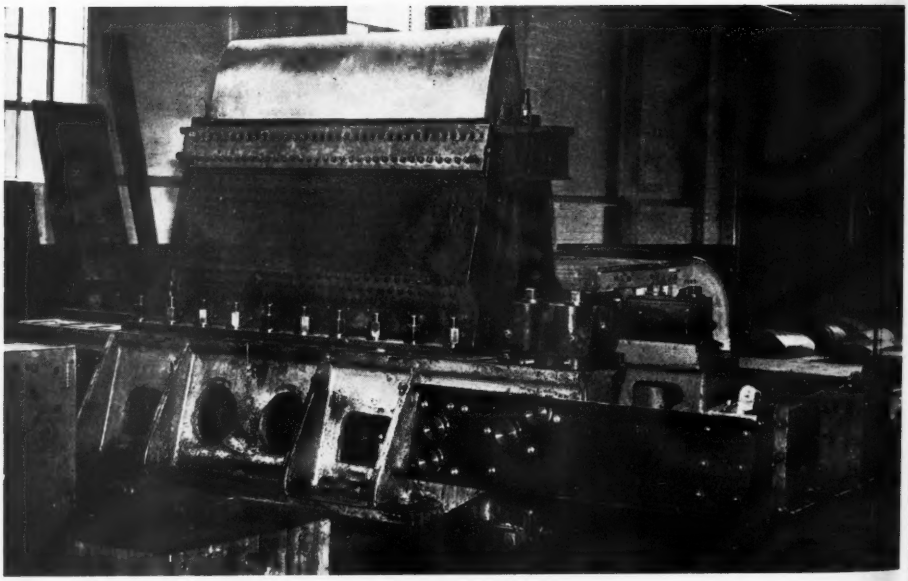


Fig. 109.
The leading edge.



Figs. 109 (*top*) and 111 (*above*).

The production of the leading edge (Fig. 109) presented one of the more difficult problems because of the extreme accuracy (0.01 in.) of contour that had to be achieved. This was solved by the manufacture of stretcher press tools in Remak metal, spar milled to the tolerance (Fig. 110 *top left on opposite page*) and set up on the Erco stretcher press (Fig. 111).

Fig. 110.
The Remak metal stretcher press tools used for the manufacture of the wing leading edges to a tolerance of 0.01 in. (*See also* Figs. 109 and 111.)

Fig. 112 (*above*).
A section of a lower wing panel, showing the stringers Reduxed in place.

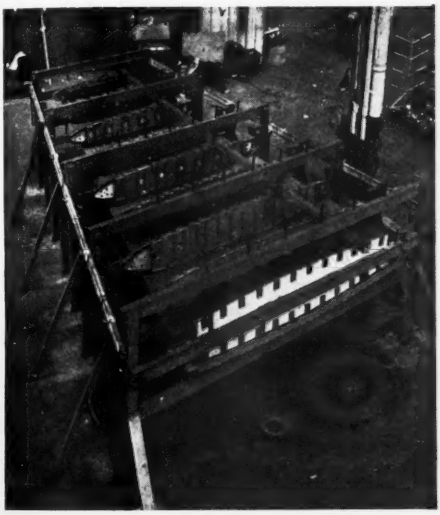
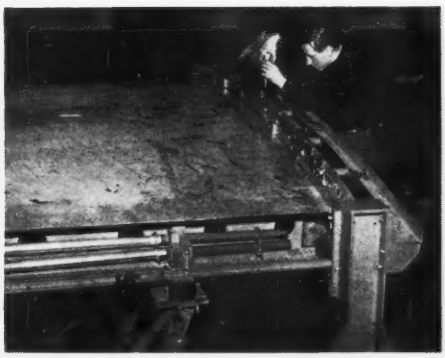


Fig. 113 (*left*).
The jig used for the construction of the outer extension of the wing.



Figs. 114 (*above*) and 115 (*left*).
The extension wing attachment holes of a stub wing being drilled while it is in position on the main drilling jig is shown in Fig. 114. The same holes locate the simple portable "trueing-up" router jig, shown in Fig. 115 (*left*), which "trues-up" the mating edges of the wing skins.

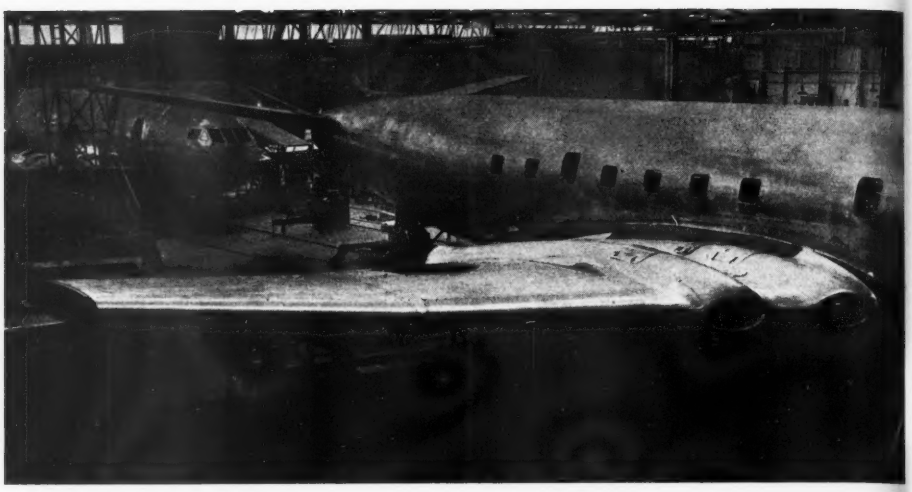


Fig. 116.
A stub wing is wheeled on its trolley into position by a fuselage ready for attachment.

tolerances, does really present a production problem. This was solved by the manufacture of stretcher press tools in Remak metal. These were spar milled to the tolerance (Fig. 110) and by a special set up on the Erco stretcher press (Fig. 111) leading edges have been successfully and economically produced to the accuracy required.

The extension wing consists of two skins with Reduxed stringers made in an orthodox jig. The skin is shown in Fig. 112 and the jig in Fig. 113.

Interchangeability between the stub wing and the extension wing joint has been achieved in a simple manner. This consists of jig drilling the extension wing while in the main drilling jig (Fig. 114) and using these holes for locating a simple router jig (Fig. 115), which produces the interchangeable mating edges of stub wing and extension.

The stub wing, when it has passed round the track and all operations are completed, as shown in Fig. 116, arrives at a station where it is wheeled into a position adjacent

Fig. 117.
Some of the fibreglass components used in the Comet. Apart from its light weight and dielectric qualities, fibreglass cloth is reasonably impervious to moisture absorption. This form of construction enables the most complicated shapes to be manufactured.

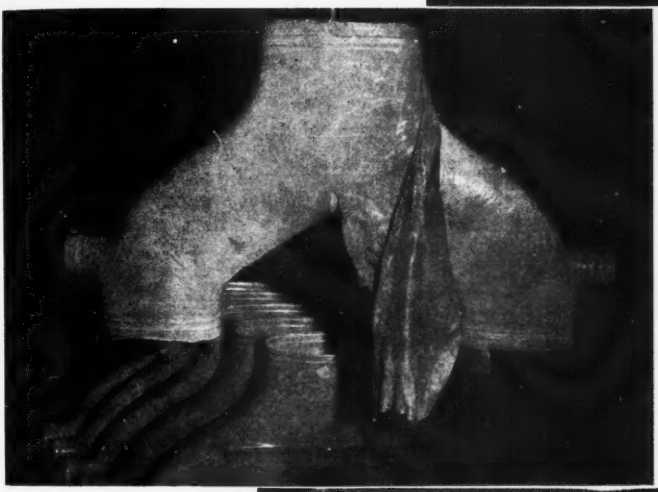


Fig. 118 (*top left*) shows a finished fibreglass component—the junction of the port and starboard ducts of the cabin air-conditioning system, and Fig. 119 (*above*) shows the two plaster cores used for the fabrication of the part shown in Fig. 120 (*left*). This has a lamination of glass cloth, tailored to size and impregnated with Nuron resin, which is shown being stretched over a plaster model. Some finished parts, which form part of the ducting for the cabin air system, can be seen in the background.

Fig. 121 (*right*) shows how a glass cloth moulding is used to support the lagging of a metal duct for the cabin air heat exchanger system.

Fig. 122.
A collapsible permanent metal mould used on the more simple components made of glass cloth.

to the fuselage, and is attached to the fuselage by the fish plate joints of the centre section.

The complete track operations include engine installation, coupling of flying controls, operation of flying controls under power, final inspection, and clearance of snags for flight.

There is not time to deal with the production and manufacture of internal equipment, but a brief account of the development which has been made by the Company with the production of glass cloth mouldings may be of interest. Fig. 117 shows a number of the large components manufactured in glass cloth, and the next figures give a close-up of some of the more difficult components.

Figure 118 shows the breeches piece which was the first attempt at serious moulding in glass cloth. The glass cloth is tailored, and then impregnated with Nuron resin, after which it is built up in laminations on a plaster core (Figs. 119 and 120) to the correct thickness.

The laminations are held in position on the plaster core by a rubber bag which is exhausted by a vacuum pump, and the whole unit is baked in a muffle at 120°C. After curing, the internal plaster core is finally broken away and the component is complete. Fig. 121 shows glass cloth mouldings which are used as an external means of supporting glass cloth lagging to heat exchanger pipes.

Other methods of moulding have also been used, and in many instances metal moulds (Fig. 122) were used which can be collapsed and withdrawn from the finished detail and finally reconstructed, thereby avoiding the loss which occurs with the plaster core, which is entirely destroyed.

Extensive use has also been made of high tensile light alloy castings which a few years ago would have been impossible, and in this respect the author pays tribute to the development of casting technique in Great Britain which has made this possible. His opinion is that production is now greatly benefiting from the courage of designers in calling for castings instead of forgings, but that more knowledge of casting and moulding technique is required by designers to eliminate some of the complications which are now encountered by pattern makers and moulders.

The photographs, which appear to be devoid of workmen, might be thought to indicate lack of activity in the factory, but it was thought better to photograph the various jigs while they were not in operation, rather than to obliterate some of the salient points by showing workmen at their job.

In conclusion, the author wishes to record his thanks to those members of his staff who assisted in the preparation of this paper.

DISCUSSION

R. H. Chaplin (*Fellow*): How did the glass cloth moulding compare in weight with ordinary light alloy pressings? He could appreciate the advantages in manufacture, but would like to know how it compared with light alloy for strength and weight.

R. E. Bishop (de Havilland Aircraft Co. Ltd., *Fellow*): He would like to amplify the importance of liaison between the Drawing Office and Production Department. His Company had gone quite a long way to foster the right feeling between Design and Production, and to achieve this Mr. Povey had stationed several production engineers in the Drawing Office so that they could be available for discussion at the start of any new type which was being designed.

The production engineers were an exceptionally good guide to the draughtsmen and as they saw practically all the drawings before they were issued to the shops this gave them a good chance to decide at an early stage if the designs were practicable and what type of tools would be needed to produce the parts satisfactorily.

This association between Production and the Drawing Office was a very good system, and the mutual advice was invaluable and paid a great dividend.

Sir John Buchanan (Past-President, *Fellow*): What was the merit of the Redux method of joining metal over the ordinary and normal method of riveting? Did they gain in weight, in strength or in reduced costs?

It would seem that the extensive use of concrete tools tended largely in the direction of economy in cost, because he presumed that a great many of the concrete tools were not chargeable with the man-hours of tool makers.

Also, horizontal jigs were used in making the wings instead of the more orthodox vertical jig. How far was it economical to have men working above their heads rather than to have them working at waist height? All the experience of motion study suggested that it was more economical for men to work at waist level because of the lack of fatigue.

The manufacture of components in glass cloth had interested him considerably. It seemed to be a better method than the present one of pressing in a light alloy, but why glass cloth? Why not a less expensive fabric? In heat exchangers where there were high temperatures the use of glass cloth was obvious, but if his memory were accurate, in the old days of the Empire flying-boat, the air ducts were made of canvas tubes doped over. This was a much lighter material than glass cloth and it was equally suitable for the purpose if there were not high temperatures.

Mr. Holly: Had there been any difficulty in the Redux process with differential expansion due to the temperature difference at which it was worked and at which the tools were put on and taken off?

Miss A. Kennedy (*Companion*): Was the new method of production broken down as easily into semi-skilled work as the old method?

W. Thorn: Had Mr. Povey tried the autoclave for Reduxing stringers to double curvature panels?

N. J. Hancock (*Associate Fellow*): What method was used in levelling up all the Vee blocks which were installed on the floor over a large area; how did they get them level and within what degree of accuracy?

The accuracy which Mr. Povey had succeeded in getting on the fitting of the wing to the fuselage and the matching of the diagonals to within 0.4 of an inch was amazing. He did not doubt it, but he had a recollection of some 25 years ago when, as a junior Inspector, he believed they used to accept something like five times that error on an aircraft only a fifth of the size — it was before the Tiger Moth.

J. A. C. Manson (*Fellow*): He had been lost in admiration of the work which Mr. Povey had described to them. The technical and production interest of the work was undoubted, but what of the financial aspects? Was Mr. Povey at liberty to tell them anything of the economics of it; the cost of the tools in relation to the aircraft or anything like that?

R. E. Hardingham (Air Registration Board, *Fellow*): He had been most impressed by the wonderful description of the building of a very wonderful aeroplane. He would be quite happy when the aeroplane eventually attained its Certificate of Airworthiness in the Normal Category for the carriage of passengers, having seen the thoroughness of the methods of production.

Could Mr. Povey say how the Redux bonding system lent itself to repair in the field ?

The President: Mr. Povey had brought some specimens of components which they might like to examine.

A first class aeroplane could provide all sorts of uses which were not contemplated probably in its original design and the Comet, apart from being one of the world's classic aircraft and a great pride to Great Britain, was certainly capable of providing, among other things, a first-class lecture. Two more lectures on other aspects of that aeroplane were planned for the next session, for which Mr. Povey had set a high standard.

In reflecting on Mr. Povey's earlier career as an Inspector, he thought there was an indication that a man who set out to inspect other peoples' performance, provided that he had had a proper engineering training, was led ultimately to become a first-class production man.

MR. POVEY'S REPLY

Mr. Chaplin: He was not a scientist or a designer — he merely produced bits and pieces, but the weight in relation to components manufactured in light alloy was on the right side, and in many cases an appreciable economy was effected by using glass cloth.

With regard to comparisons of glass cloth with pressings they had to balance things out as they would in all other types of construction. In some cases it was extremely economical and in others it might be exceptionally difficult.

One of their most advanced glass cloth mouldings was a spinner which had been designed for a propeller. The spinner was moulded in one piece, and was considered a great achievement.

Glass cloth mouldings were capable of rougher handling than components made in light alloy, and could not be damaged to the same extent from rough handling.

He had several specimens made up in glass cloth which could be examined after the meeting, but before they could say which way was best all the factors involved must be taken into consideration.

Sir John Buchanan: He thought he was right in saying, and hoped Mr. Bishop would bear him out, that in the case of the Redux method of joining metal a definite economy in the strength for weight ratio had been effected.

He had great confidence in Redux as a method of attaching metal to metal.

A partial failure might take place during processing, and in cases where it had been necessary to remove stringers from the skins extreme difficulty had always been found in their removal.

With regard to cost, on the Dove aircraft it had been established that Reduxing stringers to skins was approximately one-third that of riveting, but in the case of more complicated systems and structures the cost could only be judged on the merits of each case. Generally it was regarded that Reduxing was equally as economical as riveting.

He believed that the principal reasons for using glass cloth lay in two main features. First of all, that it was practically non-absorbent of moisture and from that point of view was extremely useful, and secondly, that it added strength to the structure. He was not altogether sure of that point, but he thought it was considered to be a stronger material than fabric. There was no reason why any of the fabricated components could not be made of fabric, or linen. He had done quite a lot with other materials and remembered quite well that on the flying boats similar parts were made in fabric.

They had now been able to produce a stronger job by the use of glass cloth which they considered to be desirable, both from the non-absorbent qualities and for strength.

As a result of a large plaster model of the wing made in a vertical position they came to the conclusion that had they built the jigs vertically the fatigue factor alone would have resulted in loss of economy. Working on ladders and platforms 16 ft. high was not conducive to good workmanship. The result of building the wings horizontally eliminated fatigue by enabling the operator to work at the correct height.

The last wing to go out of the shop was tested and no leaks in the fuel compartments were observed—a tribute to good workmanship and jigging. This method of construction on horizontal jigs did give the operators a chance. Operators might be blamed if anything went wrong because of bad workmanship, but in this jig construction they had been given a chance to show what they could do and had done it well. He believed the operators in England were as good as any in the world today, and could produce a good

job given good jigging and engineering, and a proper lead from the management.

Mr. Holly: That was a most awkward question to answer, but the answer was, "Yes." He would not attempt to describe the method of overcoming the difficulty, and could only say that it had been solved. It had been one of their difficult problems. They could now produce any Redux bond desired without any effect due to differential expansion between the components which were being bonded together.

Miss Kenedy: He thought that in all instances it depended on the ingenuity of the tool designers and the co-operation that could be obtained from the Design Section. Given time and money, and the necessary encouragement, they could break down any component to enable them to use a large percentage of semi-skilled labour. Semi-skilled labour rapidly became skilled on a particular job of work. When considering this factor it should be remembered that they might become skilled on the one job only, and that that had been made possible by the assistance of the engineers. Take them to any other job and they again became semi-skilled until trained in the new job.

Given the time and money and the right encouragement they could break down the Comet construction to enable 80 per cent. or more of the operations to be made by semi-skilled labour on suitable jigs and tools.

Mr. Thorn: He had recently read the paper by Mr. Parker, of the Bristol Aeroplane Company, on the autoclave*. At the start of their development of the technique of Reduxing, the de Havilland Company had designed a very small autoclave, about 12 in. in diameter, quite a small thing. They tried quite a number of experiments in the autoclave, but the results were not 100 per cent. satisfactory. They obtained better results with the same specimen by using a flat press. They had not the time then to develop the autoclave method. Had they continued their development of the autoclave, he thought that they might still be making autoclaves instead of Comets, whereas at present they had fifteen Comet fuselages completed and three in flight. The autoclave development would have meant spending quite a lot of money to deal with large components of the size used on the Comet. They did not have the necessary encouragement at the start to proceed with it and certainly not the time. The production of the Redux tools manufactured as described was not too complicated.

Mr. Hancock: Levelling was done by a sensitive "Dump" level and a theodolite. The level was constantly checked in all directions.

The floor level was really dependent on the stability of the concrete floor, and there had been one or two cases where the floor level had been disturbed, but checking had shown that they were within $\frac{1}{32}$ in. That was what the engineers and inspectors thought, but whether this was correct or not did not seem to matter very much since the components went together very well indeed.

With regard to the 0.4 in. difference in the diagonals dimension, no one had been more surprised than he. He had witnessed the check because he found it difficult to believe, but it was not so wonderful after all because before any drilling of the wing was done it was checked up many times in the jig by Inspection until the dihedral, incidence and sweepback were dead accurate.

Mr. Manson: The financing of the Comet called for much courage. Two prototypes only were ordered by the Ministry of Supply and the financing of the balance was carried by the de Havilland Company.

The decision to spend a million pounds on tools was a decision which taxed their courage. The Managing Director felt it was better to take this risk and have jigs and tools available so that they could give reasonable deliveries to their customers, rather than spend a large sum of money on tailored jobs and at the conclusion of the present order still have no jigs or tools available. The risk taken might be regarded as an insurance and the gamble one which could have been expected of a private enterprise.

Mr. Hardingham: He was quite certain that any repairs which would normally be made in the field could be applied to the Reduxed Comet. Mechanical repair schemes had been evolved and could be applied satisfactorily. Repairs of a major nature which normally necessitated the aircraft's return to the works would present no difficulty to the Company.

* "Metal Adhesive Processes," F. H. Parker. *Journal of the Royal Aeronautical Society.* March 1951.

REVIEWS

STRUCTURAL PLASTICS. H. C. Engel, Charles B. Hemming, H. R. Merriman. McGraw-Hill Book Co. 1951. 301 pp. Diagrams. Comparative Curves. Photographs. Index. 42s. net.

This book has been presented by the authors in the widely held belief that plastics will be increasingly employed in load-bearing structures. It may well be said to be a "meeting ground" for chemists, physicists, structural engineers and designers who are particularly interested in the strength characteristics of plastic materials. The text is not highly theoretical and will also appeal to students in that the first four chapters provide an introduction to technical plastics in general.

These chapters open with a brief résumé of the theoretical aspects of high polymeric substances and pass to a discourse on the chemical structure and general behaviour of phenol-, urea-, and melamine-formaldehyde and "polymerising" resins. The widely differing properties of various reinforcing materials are discussed and a detailed account of laminated plastics is given.

Chapter Five covers present possibilities in the low pressure moulding sphere and a detailed description of this technique, enabling large stress-free parts to be produced, follows. Readers of this Journal who are connected with the design of radomes and those engaged on the development of wing and fuselage sections, flooring, fairing and ducting will find this chapter an interesting study. The technique of employing radio frequency dielectric heating is discussed as a policy but its detailed adaptation to low pressure moulding is understandably omitted.

Chapter Six deals with the theory of "sandwich" construction and includes numerous equations enabling the reader to compare stiffness and other criteria. It concludes with a summary of aircraft applications of this composite material.

The penultimate chapter presents compressed information on Structural Adhesives. Urea-, melamine-, phenol- and rescorcinol-formaldehyde are discussed. Special adhesives for metals receive the authors' attention and a good account of this comparatively new subject is given.

The book concludes with a concise study of the problems associated with the design and manufacture of a plastic radome. These micro-wave antennae covers, when employed on aircraft, conform to very exacting specifications and the approach to the difficulties of manufacture, together with a clear statement of the electrical limitations of such components, reveals an intimate knowledge of the subject.

The presentation is excellent, there being numerous comparative tables and curves, in addition to 237 references covering the whole range of subjects discussed.

THE INDUSTRIAL GAS TURBINE. E. C. Roberson. Temple Press Ltd. 1951. 162 pp. Illustrated. Index. 8s. 6d. net.

This book can be divided into three main sections, the first dealing with the general history of turbines and other power engines from 150 B.C. to recent times, the second describing gas turbine sets constructed for industrial applications in the past 20 years, and the third dealing with speculations as to future applications of the gas turbine.

In places the author has attempted the difficult task of explaining the technical background of gas turbine design in language understood by the "average reader." Few serious-minded industrial engineers attempting to familiarise themselves with the potentialities of the gas turbine will appreciate reading that a metal gets weaker at high temperatures because of "a phenomenon associated with increased thermal agitation and relaxation of the strength of intercrystalline bonds," and might easily be confused by the author's use of such terms as "static" and "total" temperature, which are not terms generally used outside the aircraft or gas turbine industry.

The book would not suffer by eliminating these digressions into technical language.

More advanced students would also quarrel with some of the statements made, particularly the one on page 69, stating that the thermal efficiency of a simple gas turbine cycle reaches a maximum at 4.0 : 1 pressure ratio.

This book does, however, give a comprehensive review of industrial gas turbines in existence and indicates that, despite the difficulty in most applications of making a clear case at the present time for the superiority of gas turbines over equivalent steam or diesel sets, manufacturers are prepared to spend time and money in investigating this new form of prime mover in a practical experimental way.

In the final chapters where the author struggles with obvious difficulty to point a case for the future of the industrial gas turbine on economic grounds, one feels that the history of the aircraft gas turbine is being repeated in the industrial field. In logical argument new ventures are usually doomed to failure on economic grounds and the enthusiastic advocate must resolutely close his ears to reason and rely on courage and the "feeling in his bones" to carry him on till the economics of the situation obligingly change in his favour.

METALS AT HIGH TEMPERATURES. Frances Hurd Clark. Reinhold Publishing Corporation, New York, 1950. Chapman and Hall, London, 1950. 372 pp. Illustrated. Index. 56s. net.

The author states, in introducing the book, that it has been her intention to compile information recently made available on the properties of metals at elevated temperatures, and to present it for the use of the design engineer. Industrial uses of metals at high temperatures have greatly increased in recent years and the objective is a most important one. The author mentions that data on properties of metallic materials at elevated temperatures have not, up to the present, been available in any single source. By a strange coincidence G. V. Smith's "Properties of Metals at Elevated Temperatures" was presumably in preparation at the same time as, and was actually published shortly before, the work at present under review. Although there are so few modern books on the subject, there is a vast amount of information published in papers in the scientific and technical journals of the various countries of the world, and the rate of release of information on high temperature materials and related subjects is increasing rapidly. To the industrious authors who undertake the difficult task of surveying the rapidly changing technology of high-temperature alloys, the wide field of designers, users, and alloy manufacturers should be truly thankful.

In the first chapter the author gives a general introduction to the subject and to some of its theoretical aspects. The behaviour of metal parts at high temperatures under stress depends more upon the plastic properties than upon the elastic. A good introduction to the study of metal plasticity is given, the author following the lines of Prager and Nadai in connection with combined stress, and Becker, Orowan, and Andrade in the formulation of transient creep. The general outline of dislocation theory is given in a couple of pages and in about the same space the author discusses grain boundaries, fracture, and precipitation of micro-constituents. At the end of the chapter, references to important original papers dealing with special subjects touched on or dealt with more fully in the preceding text are given, and the same useful practice is followed in later chapters.

Test methods and equipment for elevated temperature studies are discussed in the next chapter. The author deals with creep tests and stress rupture tests in detail. The text states that a test period of at least 10 per cent. of the service life is preferred. Many British users prefer test periods representing a much greater percentage of the service life required and will be interested to note that the author later mentions that while short cuts to abbreviate the testing period are attractive in view of the difficulties and expense of carrying out creep tests over very long periods, it is unsafe to extrapolate data which plot as straight lines on logarithmic stress and time scales into the future. The large amount of creep data available in recent years makes it evident that the facts do not warrant such a procedure. Equipment for creep and stress-rupture test work is described in the text. Brief

reference is made to short time tension tests, the Hatfield "time-yield," the D.I.N. (D.V.M.) standard, Barr and Bardgett tests, creep tests with vee-shaped specimens, torsion creep tests, creep tests of notched specimens, hot fatigue tests, hot hardness tests, etc. U.S. standards for creep testing are given, but not British.

The later chapters of the book consist mainly of a presentation of published data on creep and strength properties of metals and alloys at elevated temperatures, covering in turn carbon and low-alloy steels, chromium-irons, austenitic steels, cobalt-base alloys, nickel-base alloys, and low melting alloys. Most of the special heat-resisting materials for which data are given are of U.S. manufacture and the text may be said to give a general collection of data on U.S. alloys. Compositions, treatments, creep and stress-rupture properties are given for the various materials and fatigue data also in many cases. There are references to British work and materials, *e.g.* for G18 B, some of the neat and informative data of Oliver and Harris is given. The main interest of the high temperature data given lies in the collected values for the U.S. materials such as Discalloy, K42B, N155, S590, S816, 411-19, Vitallium, Hastealloy, 19-9-DL, 16-25-6, etc. The data on magnesium-rich and aluminium-rich light alloys are drawn exclusively from U.S. sources.

The difficulty of experts in other countries in keeping themselves informed about British developments and research in the high temperature materials field in the past is readily appreciated, as the papers describing new work have appeared in the pages of many different journals, proceedings of technical and scientific societies and so on. The Symposium on High Temperature Steels and Alloys promoted by the Iron and Steel Institute and held recently in London (19, 20, 21 February 1951) however has materially changed the position. Its proceedings will do much to assist those in all countries to gain a good general picture of the present position of work in the United Kingdom in this important field.

Frances Clark's book includes useful chapters on manufacturing processes and techniques, and on scaling. It is well printed, with few errors of detail, and has a useful general index.

THE BIG SHOW. Pierre Closterman, D.F.C. Chatto and Windus. 1951. 256 pp. Illustrated. 12s. 6d. net.

"We are the playthings of universal incoherence. We are individual stones in a mighty edifice, whose completed design shall need more time and more peace to see in its proper perspective." With these words, quoted from St. Exupery, the author eventually discloses the key to a book written with deliberate elimination of any focus afforded by retrospection.

The Big Show is the war-time biography of one of the handful of Frenchmen who came to England when France fell. Derived from a diary, retaining all the impact of a journal pre-occupied with the passing moment, it reveals an amazing career. Writing with dramatic yet unexaggerated talent for descriptive phrase, Closterman vividly communicates the excitement and strain of combat when "unaided, alone, each of us every day had to conquer the stab of fear in his breast to preserve and reform our ebbing strength." He flew 420 sorties, miraculously surviving to tell the story of strikes against flak ship, aerodrome, or flying bomb, with combat among tree tops or high in the skies of France, sometimes fighting single-handed, but more often in massed air battles where life or death depended on luck backed by perfect judgment.

When the Armistice came the snapping of nervous tension was like a surgical operation. Fatigue and disillusion were greater than relief. That night Closterman sat silent with a friend in the deserted mess. Presently the ghosts crept back. "I swear they were all there, round us in the shadows and cigarette smoke, like kids who have been unjustly punished. Mackenzie . . . Jimmy Kelly . . . Mouse Manson . . . Young Kidd . . . Bone . . . Shepherd . . . Brooker . . . Gordon . . . dark uniforms too, with tarnished gold stripes . . . Mézillis . . . Béraud . . . Pierrot Degail —all those who had set off one fine morning in their Spitfires or their Tempests and who hadn't come back."

The Big Show may not be one of the important books on a war that has shaken the world to its foundation, but it is a very human document completely expressive of the high courage and ever gallant fellowship of Fighter Command.

WORLD AIRLINE RECORD 1950-51. R. R. Roadcap. Chicago. 1951. 263 pp. Illustrated. $9.75 net.

The editors have set themselves the task of providing a review of airline operation in the post-war period. Actually the title is somewhat misleading, since the data given refer exclusively to the period up to the end of 1949, and cover only about 75 per cent. of the world's airline network.

The information collected is mostly financial and has obviously been compiled with an eye on the American public—of the 263 pages not less than 200 are devoted to U.S.A. airlines. Even allowing for the preponderence of American civil aviation, this seems somewhat out of proportion.

Perhaps the most interesting information contained in this volume is given in the diagrams showing the density of air traffic in North America. From these one can see that the bulk of air traffic tends to be concentrated between large centres of population over medium distances, just where surface transport is best developed, and not over long distances or where other means of transport are slow or lacking, as was expected at one time. The only exception seems to be trans-Atlantic travel. It would be most interesting to have similar information for the other continents.

For the U.S.A., the type and number of aircraft used by each company and their exploitation is given, but for the other airlines this information is generally missing—one wonders why. It appears that the bulk of the world's air traffic is carried by about 800 four-engined aircraft, all, except a few dozen, American. Considering that within five or six years the majority of them will have to be replaced by new types, the outlook for our turbo-prop and turbo-jet airliners should be quite promising.

CORRESPONDENCE

INDICATION, MEASUREMENT AND CONTROL OF ICE ACCRETION

In his paper (JOURNAL, June 1951) Air Commodore Lucking did not mention the thermal ice detector, proposed by J. K. Hardy and under development at R.A.E. This instrument consists of two heated bodies (small cylinders), one exposed and the other in a sheltered position. On entering a cloud the small water droplets strike the exposed body and cool it relative to the dry sheltered body; the cooling produced being proportional to the concentration of water in the atmosphere.

A model instrument, working on this principle, has been made at the R.A.E. for icing research work; it has been provided by icing tunnel tests and is now installed for flight tests. The instrument gives an instantaneous response on entering a cloud, but the thermal inertia of the exposed body adds a small delay of some 10 seconds before a steady reading is achieved.

All the instruments described by Air Commodore Luckling require a time to allow the ice to build up on a body before any signal is given, whereas the thermal detector has the great advantage of giving an immediate response to icing conditions, as well as indicating the severity.

F. J. Bigg, *Associate Fellow*

We are sorry that the N.A.C.A. report (A simplified instrument for recording and indicating frequency and intensity of icing conditions encountered in flight, P. J. Perkins, S. McCullough and R. D. Lewis, N.A.C.A. R.M.E. 51E16, July 1951) on the N.A.C.A. Pressure-Type Icing Rate Meter was not published prior to Air Commodore Lucking's paper.

This instrument is a further development of the differential principle used in the Smith Ice Indicator but the trouble concerning choking of the air-bleed holes on the pressure side with debris or water has been eliminated through the unique design of the multi-hole sensing element. Further, it is believed that the heating cycle which varies with icing intensity is a feature that has eliminated freeze-up under severe icing conditions and burn-out under mild icing conditions. It should be pointed out that the variable heating cycle makes it possible to calibrate the instrument to give icing-rate and liquid water content in addition to its usefulness as an ice-warning indicator.

The usefulness of this instrument to collect statistical icing data was demonstrated during the past icing season and plans are being made to make a study of icing conditions throughout the United States over the major air routes. Mr. Peter Hadfield, Assistant to the Civil Air Attaché, British Embassy, Washington D.C., will be kept informed of the progress of this programme.

Ira H. Abbott,
Assistant Director for Research,
National Advisory Committee for Aeronautics.

AIR COMMODORE LUCKING'S REPLY

Although I knew about the R.A.E. thermal ice detector, on which Mr. Bigg has been working, when I wrote the paper I did not mention it because I regarded it as coming within a security classification. I am now assured by Mr. Bigg that it is free of any such restriction.

Thermal detection as exemplified in the R.A.E. detector has the advantages of entailing no moving parts, and of lending itself to neat and compact construction. I believe, however, that it will prove very difficult to make such an instrument respond in due measure to all the many factors affecting the rate of ice accretion. It should certainly respond well to what are now generally believed to be the two major factors, atmospheric water content and temperature: possibly, for operational purposes, all the other factors may be ignored. On the other hand, if we have an instrument that responds to actual ice accretion, one that indicates, directly or indirectly the heat required to prevent it, or to keep it in check, we may be free of concern as to what atmospheric factors and others are at work. For research purposes, of course, we require instruments to measure all the separate factors and, at the same time, the actual rate of ice accretion that follows from them.

I now wish to refer to the question of lag and to say that I am confident that a mechanical instrument of some such pattern as those described in my paper, could be developed to have, under severe icing conditions, less lag than the 10 seconds mentioned by Mr. Bigg in relation to the R.A.E. instrument. The less severe the conditions the greater the lag, and this, I submit, is what is wanted, so long as the metering surface is at least as good a collector as any part of the aircraft.

I take this opportunity of referring to an instrument, a description of which has only recently reached me. It has been developed by the N.A.C.A., and a number of examples have been in use by U.S. airlines. It is intended to put an improved version of this "N.A.C.A. Pressure-Type Icing Rate Meter" into extended use next winter. It follows the differential principle that some of us favour and employs two pitot heads, one of them continuously anti-iced, the other intermittently de-iced, that is, whenever it becomes plugged, heat being applied to it when the pressure in the static-vented chamber to which it is connected falls below that of a pressure chamber connected to the anti-iced pitot head. Icing encounters are indicated to the pilot and recorded photographically, the length of the icing period being read as an indication of icing severity. The instrument has much in common with the Smith Ice Detector but their methods of using differential pressure are not the same.

D. F. Lucking, *Fellow*

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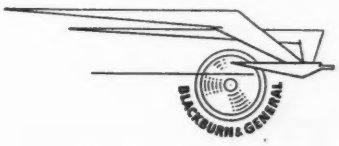

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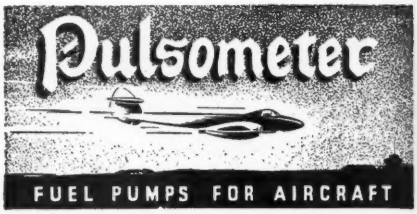

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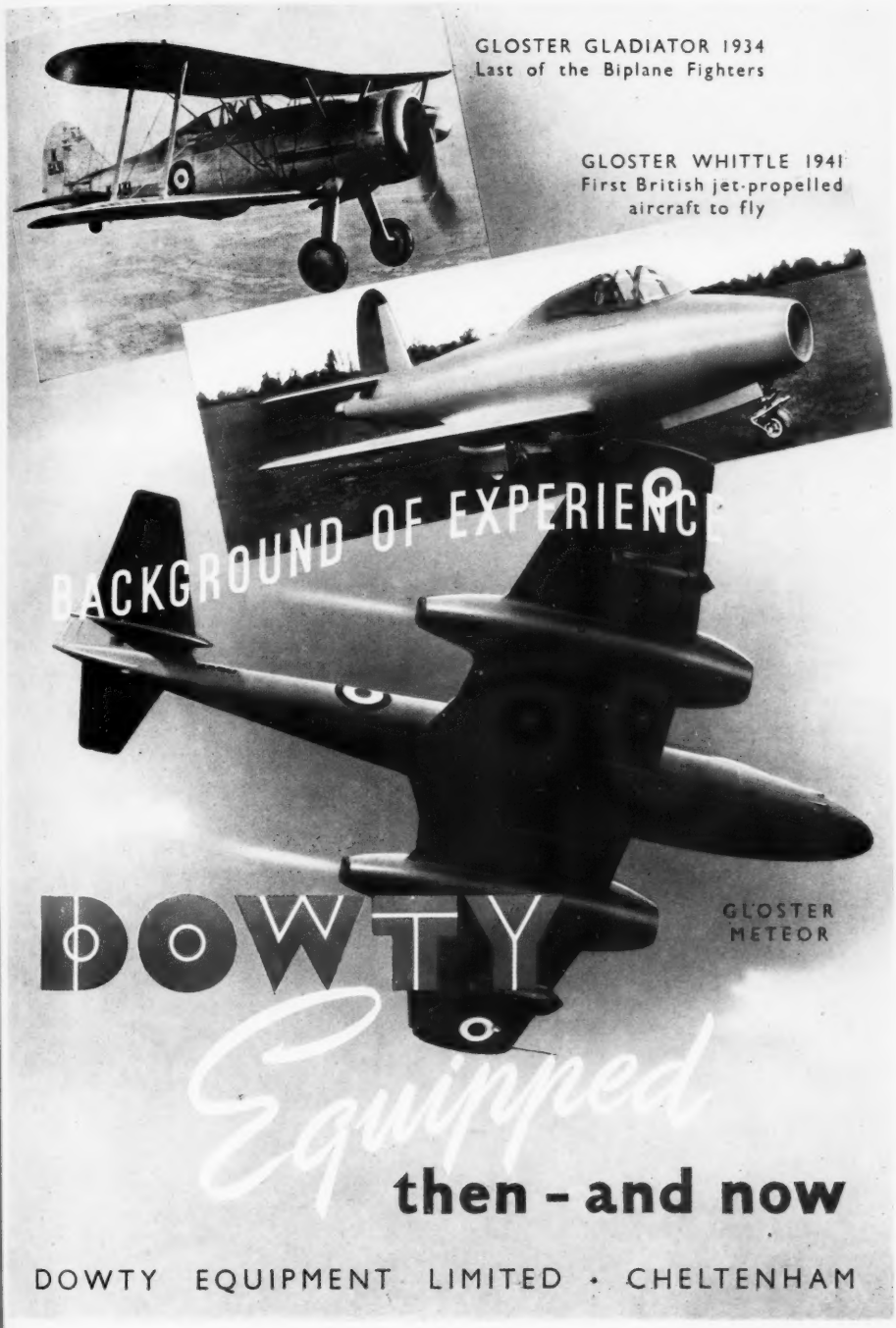
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